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Introduction

This document provides basic guidelines for how to select a suitable AEM Components SolidMatrix® and AirMatrix® SMD fuse. This guide makes certain assumptions regarding the customers application, and as such, it is incumbent on the engineer to further validate their selection, through the use of additional testing and analysis.

As part of this process, it is important that reader have a basic understanding of how fuses work within the circuit:

- Under normal steady state operating conditions, a fuse should behave as if it is invisible to the circuit.
- If an overcurrent event occurs, the fuse is intended to prevent current flow and protect important components downstream.
- Operation of the fuse is temperature dependent, and this temperature is influenced by the amplitude of the current and the time at which the fuse is exposed to an over current. If the over current level, or time, exceeds the point at which damage to these sensitive components may occur, the fuse is intended to open, halt the current flow and protect those components.
- The fusing element or conductor within a typical fuse is made of metal, with copper being the most common. Current flow is interrupted when the temperature of the metal increases to the point where it melts.
- Even if a fuse were to open as intended, intermittent current flow may still be present within the circuit, if the maximum operating voltage is higher than the voltage rating of the fuse. Fuse voltage rating is governed by the size of the fuse and the clearance between opposing ends of the fuse element, after the fuse opens. If the operating voltage is higher than the fuse rating, than arcing across the open fuse may occur.
- Depending on the application, two similarly rated fuses can have different fusing characteristics, where one fuse could be designed to open very quickly, and the other may be intended to take longer. Generally referred to as Slow Blow or Fast Acting fuses, selection generally comes down to the type of circuit and how sensitive your downstream components might be to this overcurrent event.

Selection Parameters

Proper fuse selection is governed by 3 basic parameters, which include *Steady State Conditions*, *Transient Conditions* and *Safety Standards and Regulations*. These parameters help to define the Upper and Lower limits for the fuse current rating and depending on a customer's specific application, all of these parameters will need to be considered to some degree while determining the final fuse selection. See Figure 1.

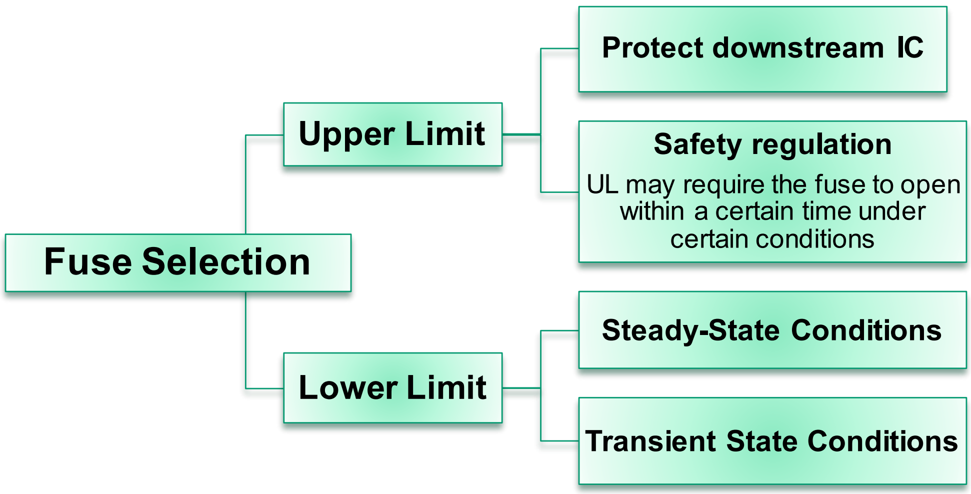

Figure 1 – Fuse Selection Methodology

1. Steady State Conditions

1.1. Maximum Steady State Operating Current (I_C) vs Fuse Current Rating (I_f)

The maximum current of a circuit while functioning at steady state conditions, is called the Operating Current (I_C). In accordance with international standards, fuses must be able to function at the maximum steady state operating current and an ambient temperature of +25°C, for at least 4 hours minimum.

To ensure long-term steady state operation beyond 4 hours and to limit the possibility of nuisance blows, fuse selection should be such that the actual operating current (I_C) will be less than 75% of the fuse current rating (I_f).

$$\text{Minimum Fuse Current Rating } (I_f) = \frac{\text{Steady State Current Rating of Circuit } (I_C)}{75\%}$$

Refer to the catalog data sheets at www.AEMComponents.com for the rated current of AEM SolidMatrix® and AirMatrix® fuses.

1.2. Operating Temperature (T) and Fuse Temperature De-rating (K)

Fuse ratings are generally specified at +25°C and the electrical performance characteristics of the fuse can be affected when the fuse is operated at a temperature above, or below this temperature. For operation at a maximum temperature other than +25°C, refer to the formula below and Figure 1, on how to establish the required AEM SolidMatrix® and AirMatrix® fuse de-rating factor (K). Additional de-rating curves can be found in AEM's catalog at www.AEMComponents.com

$$\text{Fuse Current Rating @ T °C Max } (I_F) = \frac{\text{Current Rating @ +25°C } (I_f)}{\text{De-rating Factor (K)}}$$

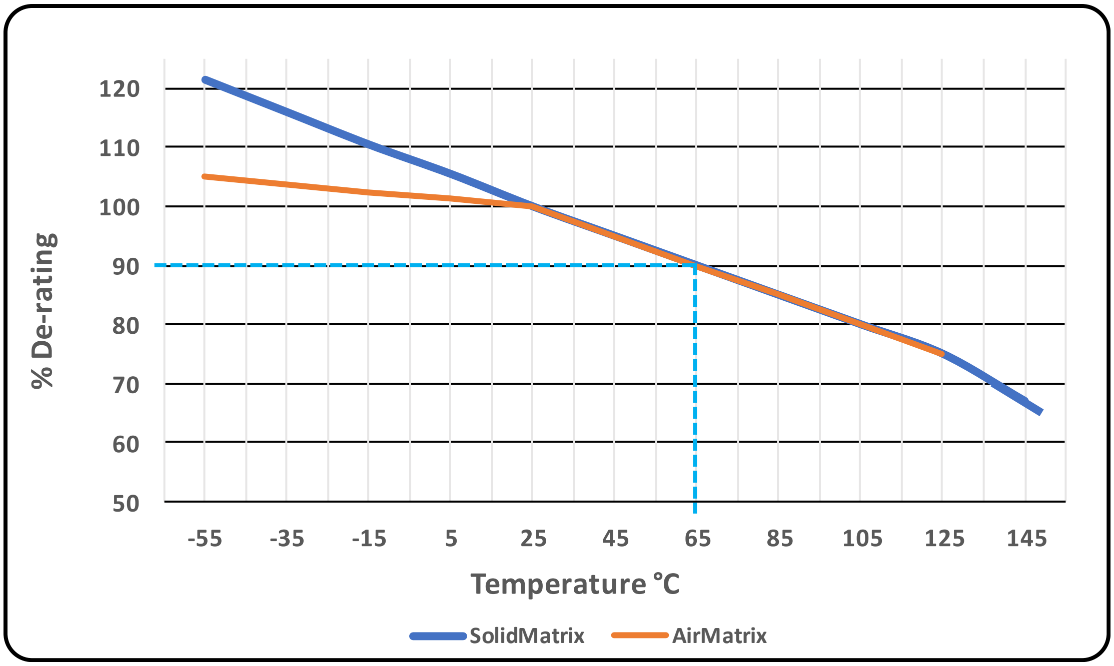

Figure 2 – Temperature Effect on Fuse Current Rating

Example Parameters:

I. Steady state operating current (I_C) = 10A
II. Steady state operating temperature = +65°C

$$I_F = \frac{I_f}{K} \qquad \text{Where } I_f = \frac{I_C}{75\%} \quad \text{\& } K = 90\% \text{ @ } +65°C \text{ (see Fig 2)}$$

$$I_F = \frac{10A}{75\% \times 90\%} = \frac{10A}{0.75 \times 0.90}$$

I_F = 14.82A min (Rounded up to 15A min for nearest standard value)

In this example and based on the above steady state conditions, a fuse rating of 15A min would be required

2. Transient Conditions

Where steady state conditions help to establish a starting point in the fuse selection process, the engineer also needs to consider any transient conditions that the fuse might be subjected to and how those transients might affect the overall performance of the fuse. When power is turned on or off for example, the circuit could be subjected to a very large inrush of current, and this momentary pulse or series of pulses, may be substantially larger than the circuits steady state value, which in turn could adversely influence the effectiveness of the fuse. Fuse parameters including Interrupting Rating, Nominal Melting Integral (I^2t), Pulse shape and duration as well as operation temperature, all need to be reviewed when considering the impact of transient conditions

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2.1. Interrupting Rating (IR)

Interrupting rating (IR) refers to the maximum current that can safely be interrupted by a fuse, while operating at rated voltage. The IR of a chosen fuse must be equal to, or greater than, the maximum fault current that the fuse may be exposed to in a circuit. In this way, the fuse may break safely without causing any collateral damage or presenting hazardous conditions.

2.2. Nominal Melting Integral (I^2t)

Nominal Melting Integral or I^2t, defines the amount of energy it takes to melt the fuse element and cause the fuse to open. Because most circuits utilize energy storage components like capacitors or inductors, a large pulse current may occur when the power is turned on, or off. In addition, a transient pulse may also occur as the result of external factors like electromagnetic reaction and generally speaking, it is the customer's expectation that the selected fuse will be able to withstand multiple pulse shocks, without heating up to the point where the fusing element opens..

In order to safeguard proper functionality of the fuse when subjected to these type of transient pulses, the Nominal Melting Integral of the selected fuse (I_F^2t) must be greater than or equal to the energy generated by the circuit (I_P^2t) and this value is dictated in large part by the peak amplitude of the pulse (I_P), it's shape and it's duration. A square wave shaped pulse for example, would generate a larger amount of energy than a saw tooth or sinusoidal waveform as total time at peak current over the same pulse width, would be less.

Table 1 below lists the I^2t formulas for common pulse waveforms. The I_P^2t value of a pulse current can be calculated from the integration of the pulse current wave data. The following example compares the minimum required I_Ft^2 for a fuse that is subjected to a square and sine wave pulse transient.

Example Parameters:

I. Peak transient waveform pulse current (I_P) = 15A peak
II. Pulse width (t) = 100 msec

I_F^2t (Square Wave) $\geq I_P^2t \geq 15A \times 15A(100 \times 10^{-3}sec) \geq 225A^2(0.100\ sec)$
$\geq 22.5\ A^2sec$

I_F^2t (Sine Wave) $\geq \frac{1}{2} I_P^2t \geq 0.5 \times 15A \times 15A(100 \times 10^{-3}sec) \geq 112.5A^2(0.100sec)$
$\geq 11.25\ A^2sec$

In this example, the required I_F^2t for a fuse subjected to a square wave would need to be twice the rating of a fuse selected for an application where the pulse wave shape is a sine wave.

As mentioned in the introduction two similarly rated fuses can have different fusing characteristics, where one fuse may be designed to open very quickly, while the other may be intended to take longer. Generally classified as either fast acting or slow blow (time-delay) fuses, performance is distinguished primarily by the I^2t level of the device and how much energy the fuse can accommodate before opening.

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Due to these differences in I^2t, fast acting and slow blow fuses are typically applied to different circuits. Fast acting fuses for example, are normally used in purely resistive circuits, where they will see very few, if any pulses, and where an IC and other sensitive components need to be protected. Slow blow fuses on the other hand, have higher I^2t ratings and take longer to open, which allows them to withstand transient pulse surges normally encountered during power on, or off situations associated with capacitive or inductive circuits.

Apart from circuits where a fast acting fuse is being applied for IC protection, most applications will allow the use of a slow blow alternative, and may in fact be more advantageous, especially where enhanced anti-surge capability is desirable. Conversely, in those applications where some type of time delay is necessary and a slow blow fuse is being utilized, replacement with a fast acting fuse is likely not an option, as the fast acting fuse may be prone to opening and create a nuisance blow condition, as soon the equipment is switched on.

Nominal I^2t ratings for AEM Components fuse products and options for both Slow Blow and Fast Acting fuses can be found in our catalog at www.AEMComponents.com.

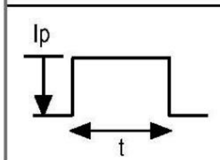
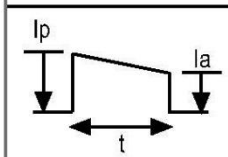
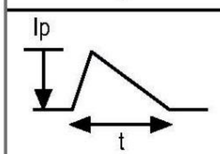
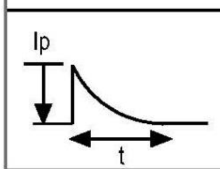
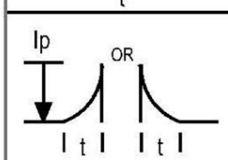
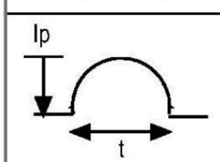
Waveshape	Formulas
	$I^2t = I_p^2 t$
	$I^2t = \frac{1}{3}\left(I_p^2 + I_p I_a + I_a^2\right)\cdot t$
	$I^2t = \left(\frac{1}{3}\right) I_p^2 t$
	$I^2t = \left(\frac{1}{2}\right) I_p^2 t$
	$I^2t = \left(\frac{1}{5}\right) I_p^2$
	$I^2t = \left(\frac{1}{2}\right) I_p^2 t$

Table 1: I^2t Formulas for Common Waveshapes

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2.3. Pulse and Temperature De-rating

As indicated in section 2.2 above, a current pulse flowing through a fuse generates heat and selection of a fuse with a suitable I^2t rating is an essential step in ensuring that the fuse works properly and is capable of managing the energy generated by the defined pulse transient waveform. That said, it is important to note that this assumption is based on the energy generated by a single current pulse and as such, further consideration needs to be given to those situations where the fuse may be exposed to multiple current transients. If for example, the time between pulses is not sufficient enough to allow the fuse element to return to its original pre-pulse ambient temperature, subsequent pulses could cause an accumulative effect, whereby the fuse element continues to heat up to the point where it opens. With that in mind, if multiple pulses are anticipated, the engineer also needs to apply a pulse de-rating factor (P) to the original I^2t calculations. This de-rating factor (P), which is shown in Table 2 for AEM's SolidMatrix® and AirMatrix® fuses, is based on the number of pulses that the fuse is expected to withstand.

In addition to the Pulse De-rating factor (P), consideration also needs to be given to the operating temperature, whereby a temperature determined de-rating factor (K), needs to be applied to the I^2t calculation, in a similar fashion to the one used for the Steady State temperature de-rating calculation in Section 1.2. Please refer to the example below on how to apply the Pulse and Temperature De-Rating factors.

Number of Pulses to Withstand	Ratio of I_r^2t Value of Pulse Current to I_F^2t of Fuse	Pulse De-rating Factor (P)
100,000	$I_r^2t \le 20\% \; I_F^2t$	**20%**
10,000	$I_r^2t \le 30\% \; I_F^2t$	**30%**
1,000	$I_r^2t \le 40\% \; I_F^2t$	**40%**

Table 2: Pulse Derating Percentage for AEM SolidMatrix® and AirMatrix® fuses

Example Parameters:

I. Nominal Melting Integral (I_P^2t) for a circuit operating at +25°C with a single sine wave pulse = 11.25 A^2sec (See calculation in Section 2.2)
II. Number of pulses to withstand = 100,000 pulses
III. Maximum ambient operating temperature = +85°C

Pulse Derating Factor (P) = $I_r^2t \le 20\% \; I_F^2t$ @ 100,000 pulses = 20%

Temperature De-rating Factor (K) @ +65°C = 90% (Reference Figure 2)

$$I_F^2t \ \ge \ \frac{I_P^2t}{\text{Pulse De-rating Factor x Temperature De-rating factor}}$$

$$\ge \ \frac{11.25A^2sec}{20\% \times 90\%} \qquad \ge \ \frac{11.25A^2sec}{0.20 \times 0.90}$$

$$\ge \ \underline{62.5A^2sec}$$

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In this example, the 11.25A^{2}sec minimum $I_F{}^2t$ required for a fuse subjected to a single sine wave pulse of 15A for 100 msec @ +25°C, would need to increase 62.5A^{2}sec, if that same fuse were now expected to withstand 100,000 pulses at an ambient temperature of +65°C

3. Safety Standards, Regulations and Circuit Protection

The final consideration in fuse selection would be the Safety Standards, Regulations and circuit protection requirements that might apply to the intended application and ensuring that the selected fuse complies with these requirements.

3.1. Clear Time Characteristics

Clear time properties of a fuse estimate the rate at which a fuse will respond to different current levels, while operating at +25°C and characteristically speaking, clear times or pre-arcing times, decrease as the current level increases. Clear times, which are often presented in tabular form, are typically listed as a percentage of the nominal fuse current rating and help to aid in the selection process. They help for example, to distinguish between a fast acting fuse, which would have a very short clear time and a slow blow, or time lag fuse, which takes a much longer time to clear when subjected to a similar overcurrent. As a comparison, a SolidMatrix F1206FA, fast acting fuse, rated for 5A, has a clear time of 5 seconds max, when subjected to 250% of its fuse current rating, whereas a F1206SB, slow blow fuse, rated for 5A, has a much longer clear time of 120 seconds max, when exposed to 200% of its fuse rating. With that in mind, if application details were to include an overload current spec and maximum clear time requirement, then these parameters will help in determining an upper limit for fuse rating. As an example:

Application Parameters:

I. Overload current = 8A
II. Clear time = 60 sec max (Characteristic of AEM's F1206HI series)

Clear Time Characteristics for the F1206HI series, establishes 8A as 200% of the fuse current rating at 60 seconds maximum. Consequently, 4A would be the upper limit, for this particular type of fuse.

Average Pre-Arcing Time curves present the same information, but provide it in graphical form, allowing for clear time estimates across a much broader range of values. These curves are particularly handy, when attempting to compare similarly rated fuse options from different manufacturers.

3.2. Voltage Rating

As indicated in the introduction, under normal steady state operating conditions, a fuse essentially behaves as a very low resistance conductor that is invisible to the circuit and in those situations, voltage rating of the fuse might seem relatively unimportant. However, if the fuse were to be subjected to an over current event whereby the fuse opens, then selecting a fuse with the proper voltage rating can have a significant impact in how the fuse behaves. A fuse voltage potential in air is dictated by the size of the fuse and clearance between opposing

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potentials once the fuse opens, and making sure that the fuse voltage rating is greater than or equal to the voltage rating of the circuit will help to ensure proper functionality of the fuse and minimize the risk for post open arcing conditions.

3.3. Safety Standards

The final consideration in fuse selection would be the Safety Standards, Regulations and circuit protection requirements that might apply to the intended application and ensuring that the selected fuse complies with these requirements. UL and IEC for example provide additional safety requirements and regulations related to specific end applications.

Selection process and Example

For the following parameter calculations, items 1 and 2 would fall under the classification of Steady State parameters, whereas items 3 through 6 would be considered Transient State.

Steady State parameter calculations

1. Rated current (I_F) of the appropriate fuse should be greater than or equal to the operating current of the circuit (I_C) and requires a standard safety factor of (I_C/75%).
2. Rated current (I_F) of the appropriate fuse needs to factor in the maximum operating temperature and requires an additional safety margin (K) that is based on the Temperature De-rating Curve (See Figure 2)

Based on the standard UL safety margin of 75% and the operating temperature safety margin (K) found in Figure 2, the minimum rated current (I_F) would be calculated as follows:

$$I_F \geq \frac{I_C}{0.75 \times K}$$

Transient State parameter calculations

3. Calculate the required I^2t value of a single pulse current by referring to the formulas for common pulse waveforms in Table 1. For more complex, or non-typical waveforms, an exact value can be obtained through the integration of data from a digital oscilloscope, or through a more simplified calculation method, whereby a similarly shaped common pulse waveform that can entirely cover the actual waveform is utilized.
4. Determine the Pulse de-rating factor (P): Based on the required number of pulses to withstand, establish the required pulse de-rating factor from Table 2.
5. Determine the Temperature de-rating factor(K): If the ambient temperature is greater than room temperature when a pulse occurs, a corresponding temperature de-rating is required and can be found in Figure 2.
6. Based on the final $I_F{}^2t$ calculation, confirm the minimum current of the fuse required to withstand the number of pulses.

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Safety Standards and circuit protection requirements

7. Make sure that the fuse complies with safety standards and regulations, or circuit protection requirements, e.g. the maximum I^2t withstanding value of the protected IC, the required voltage rating of the fuse needed to prevent post open arcing of the fuse, the Clear Time Characteristics needed help prevent the circuitry from overheating, Interrupting Ratings, which ensure that the fuse opens safely, etc.

Choosing the fuse to meet your design criteria

8. Based on the results of Step 1 / 2 and Step 6 calculations above, the larger of the two rated current values determines the lower limit of the design window, whereas requirements in Step 7 help determine the upper limit. In addition, if we consider that performance variations for other components within the circuit may cause the pulse current to fluctuate, an additional allowance of 30% is generally recommended, to prevent nuisance openings under extreme conditions. With that in mind the specification of the fuse or fuses that could be selected for a specific application should fall within this design window.

Test verification

9. The specification parameters determined in the previous steps, should be verified through testing in actual circuits and in an environment that is as much as possible, similar to the actual application conditions. Full life tests should also be conducted accordance with the required number of pulses the fuse is expected to withstand.

Example

The following example further characterizes the previous selection process.

Application parameters:

a. Maximum steady operating current: I_C = 0.54A
b. Operating temperature: +65°C
c. Waveform of maximum transient pulse current (Sine wave):
   - Maximum current I_P = 45.5A
   - Pulse width t = 1.0 msec
d. Required number of pulses over life of device: 100,000
e. Overload current and corresponding breaking time = 10A, 60 sec
f. Possible maximum fault current in application: 50A
g. Maximum operating voltage 12VDC
h. Fuse Dimensions: 1206
i. Compliance standard: UL Recognized

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Step 1 - Calculation of Steady State parameters:

$$I_F \geq \frac{I_C}{0.75 \text{ (current derating factor) x K (temperature derating factor)}}$$

$$I_F \geq \frac{0.54A}{75\% \times 90\%} \geq \frac{0.54A}{0.75 / 0.90}$$

$$I_F \geq \underline{0.80A} \text{ (Rounded up to } \underline{1A} \text{ min)}$$

$I_F \geq 1A$ would be an acceptable starting point based on the nearest standard fuse rating

Step 2 - Calculation of Transient parameters:

Step 2.1.a: Calculate I^2t value, single pulse @ +25°C:

$$I_P{}^2t \text{ (Sine Wave)} \geq \tfrac{1}{2} I_C{}^2t$$
$$\geq 0.54(45.5A \times 45.5A)(1.0 \times 10^{-3} sec)$$
$$\geq 0.54(2070.25A^2)(0.001 sec)$$
$$\geq \underline{1.118A^2sec}$$

A fuse with an I^2t rating $\geq 1.118A^2sec$ would be required to handle a single Sine wave pulse of 45.5A for 1.0msec, operated at +25°C

Step 2.1.b: Determine I^2t impact of Pulse de-rating and Temperature de-rating

$$I_F{}^2t = \frac{I_P{}^2t}{\text{P (100k Pulse de-rating) x K (+65°C Temp de-rating)}}$$
$$= \frac{1.118A^2sec}{20\% \times 90\%} = \frac{1.118A^2sec}{0.20 \times 0.90}$$
$$= \underline{6.21A^2sec}$$

A fuse with an $I_F{}^2t$ rating of 6.21 A^2sec minimum would be required to meet a 45.5A, 1.0mSec Sine wave operated at a maximum ambient temperature of +65°C for 100,000 pulses.

Comparing the Average I^2t vs Time curves in the AEM Catalog, the F1206HI, 6A fuse with an $I_F{}^2t$ of $6.5A^2sec$ at 1.0 mSec, would meet the minimum $I_F{}^2t$ requirement of 6.21 A^2sec

Step 3 – Protection Performance Considerations

Step 3.1: Determine Clear Time characteristics and maximum fuse current rating based on overload current of 16A and required breaking time of 60 Sec

Clear Time = 60 seconds maximum @ 16A

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Comparing the required breaking time of 60 Seconds max to the Clear Time Characteristics tables in AEM's catalog, the SolidMatrix F1206HI series would meet this requirement. In addition, Clear Time Characteristics for the F1206HI series, establishes 16A as 200% of the fuse current rating at 60 seconds maximum, which would set an upper limit of 8A for this particular type of fuse.

If 16A = 200% I_F, then I_F upper limit ~ 8A

Step 3.2: Confirm Interrupting Rating for fuse will meet or exceed maximum specified 50A fault current for application

A review of the AEM Catalog confirms that the F1206HI, 6, 7 & 8A fuse designs have an interrupting Rating of 80A at WVDC, which complies with spec requirement of 50A minimum.

Step 3.3: Confirm that selected fuse meets with UL Compliance

A review of the AEM Catalog confirms that the F1206HI series complies with the UL certification requirement and is recognized under Components Program of UL, File No: E232989.

Step 4 – Additional Spec Considerations

Step 4.1: WVDC @ 12VDC minimum

F1206HI 6, 7 & 8 Amp fuses are rated for 24VDC which meets and exceeds 12VDC spec requirement.

Step 4.2: Package size @ 1206

F1206HI series fuses utilize a 1206 package size which meets the spec requirements.

Conclusions:

In conclusion, the Solid Matrix F1206HI fuse series rated from 6.0 to 8A, appears to satisfy all of the application parameters specified in the above example. Taking into consideration that other components within the circuit can further influence performance and introduce nuisance blows, AEM would always recommend that the final selection be made towards the upper side of the range, with either part number F1206HI7000V024T or F1206HI8000V024T being the preferred choice.

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Recommendations offered within this application note are intended to provide general guidelines for selection of AEM Components SolidMatrix®, AirMatrix®, Thin Fim and CMF SMD fuses, including automotive grade fuses. They reflect commonly accepted practices used within the industry and should, if applied properly, provide the basis for proper fuse selection. These recommendations may not be applicable to all situations and as such, should not be considered as a guarantee for proper functionality. Consequently, it becomes the customer's responsibility to confirm results and where necessary, make the required adjustments, to accommodate application specific conditions. For the most up to date information, please consult the factory.