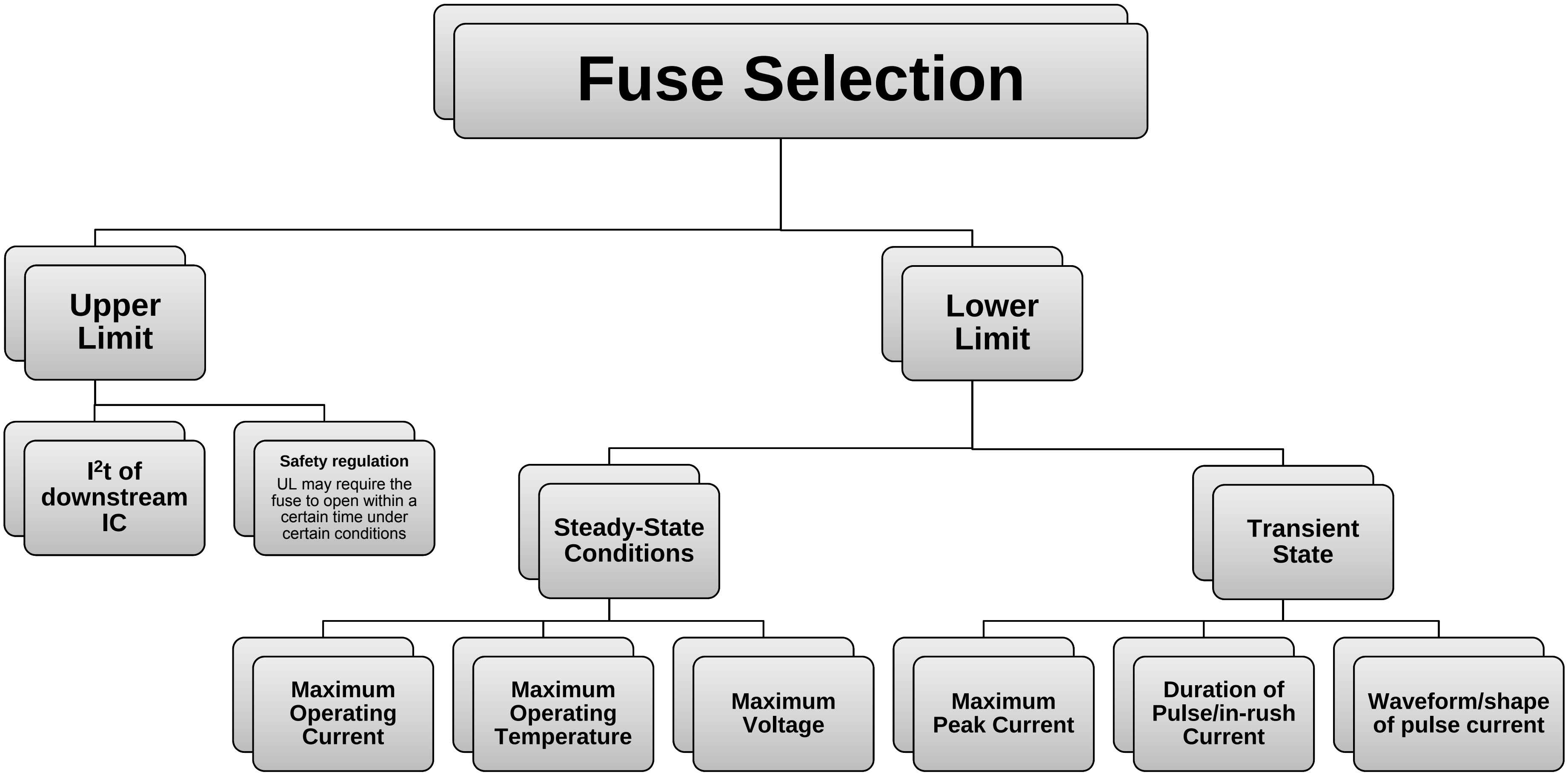
Fuses in Parallel

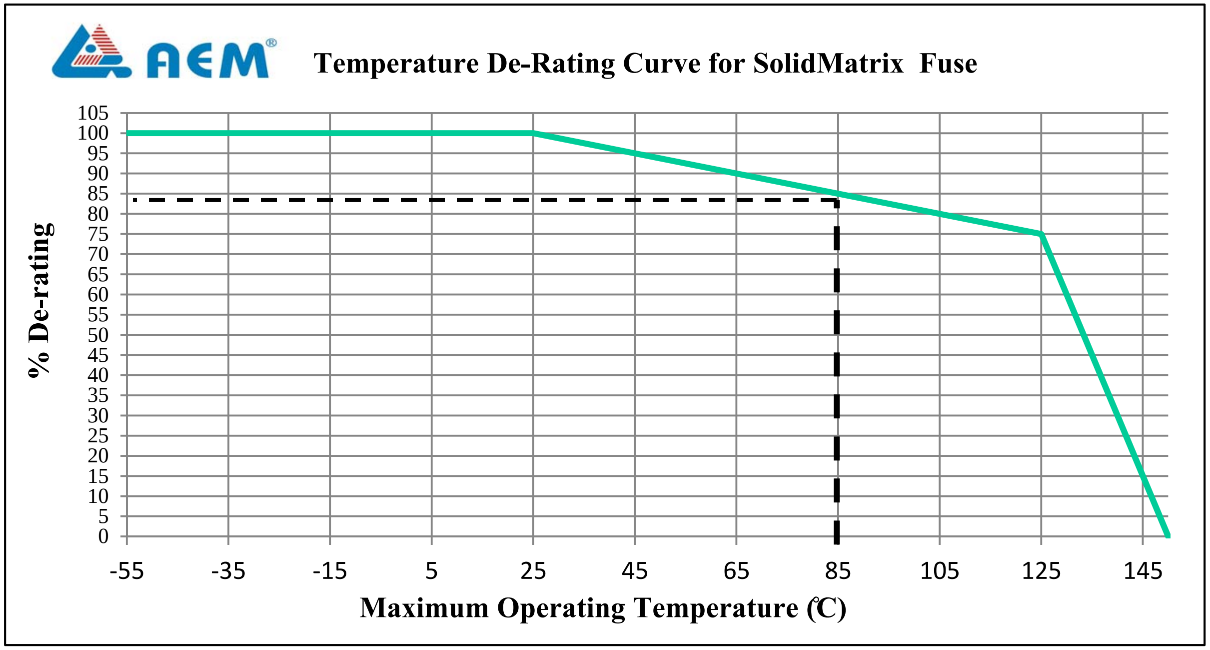

Fuse Selection
Upper Limit
Lower Limit
I^2t of downstream IC
Safety regulation
UL may require the fuse to open within a certain time under certain conditions
Steady-State Conditions
Transient State
Maximum Operating Current
Maximum Operating Temperature
Maximum Voltage
Maximum Peak Current
Duration of Pulse/in-rush Current
Waveform/shape of pulse current

Steady-State

Step 1: Operating Current
Operating current 75% or less of fuse current rating

Step 2: Operating Temperature
Temperature de-rating Chart

Step 3: Operating Voltage
Fuse voltage rating ≥ operating voltage



Example: Fuse current rating for a steady state operating current of 2A operating at ambient temperature up to 85℃.

$$I_{fuse} \geq \left(I_{operating}/0.75\right)/T_{derating}$$

$$I_{fuse} \geq \left(2/0.75\right)/0.85$$

$$I_{fuse} \geq 3.13A$$

Transient State

Step 1: Determine pulse waveform

Step 2: Calculate I^2t of pulse waveform

The energy contained in the pulse is given by:

$$I^2t = \int_0^t [A(t)]^2\,dt$$

Step 3: Pulse cycle de-rating

Stress induced by current pulse is mechanical in nature

Step 4: 30% safety margin

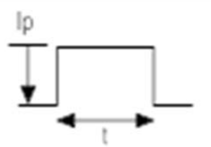
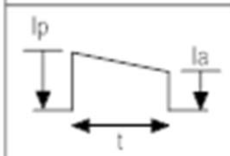
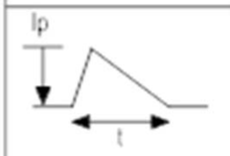
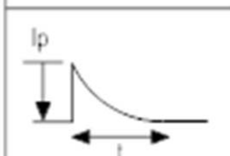
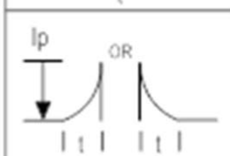
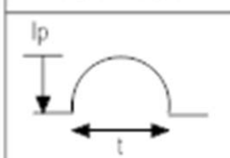
Rule of thumb 30% head room to account for variants introduced by other components in the circuit

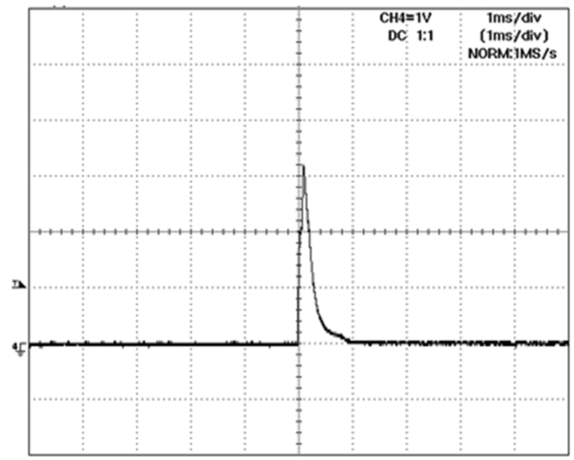
Step 5: Compare with I^2t of fuse

$$I^2t_{fuse} \geq I^2t_{pulse}$$

Transient State Example

Step 1: Determine Waveform

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



Example:
Transient pulse of capacitor discharge 100,000 cycles

Step 2: Calculate I²t of pulse

$$I = 16A$$
$$t \approx 0.0004\ sec$$

$$Pulse\ waveform\ 4 \rightarrow I^2t = \frac{I^2t}{2}$$

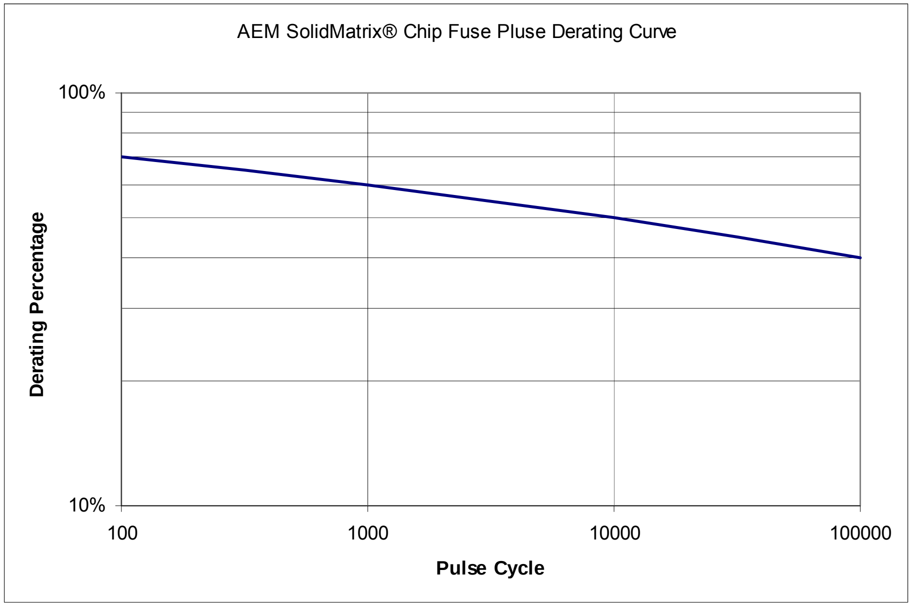
$$I^2t_{pulse} = \frac{(16)^2(0.0004)}{2}$$

$$= 0.0512\ A^2sec$$

Transient State Example cont'd

Step 3: Pulse Cycle and Temperature de-rating

$$I^2t_{pulse} = \frac{0.0512\ A^2sec}{0.4} = \frac{0.128A^2sec}{0.85} = 0.15A^2sec$$



Step 4: 30% margin

$$I^2t_{pulse} = \frac{0.15A^2sec}{0.7} = 0.215A^2\ \mathrm{sec}\ @\ 0.4ms$$

Step 5: Compare with I²t of fuse

$$I^2t_{fuse} \geq I^2t_{pulse} \rightarrow I^2t_{fuse} \geq 0.215A^2\ \mathrm{sec}\ @\ 0.4ms$$

Fuses in Parallel

Concept

- Consider a parallel resistor network (Fig.1)
- i_x can be determined through equation 1
- R_T can be determined through equation 2
- Current divider

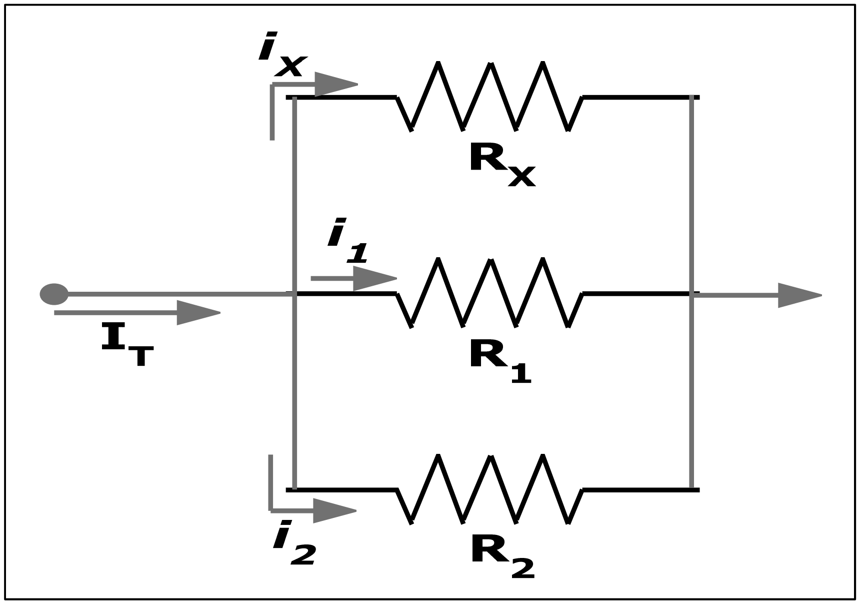


Figure 1

$$\textbf{Equation 1:}\ i_X = \frac{R_T}{R_X + R_T} I_T$$

$$\textbf{Equation 2:}\ \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots \rightarrow R_T = \frac{R_1 R_2}{R_1 + R_2}$$

Fuses in Parallel

Example: Two 25A fuse in parallel (Fig. 2)

F_1 = 25A rated

F_2= 25A rated

DCR $\pm$ 30% *tolerance*

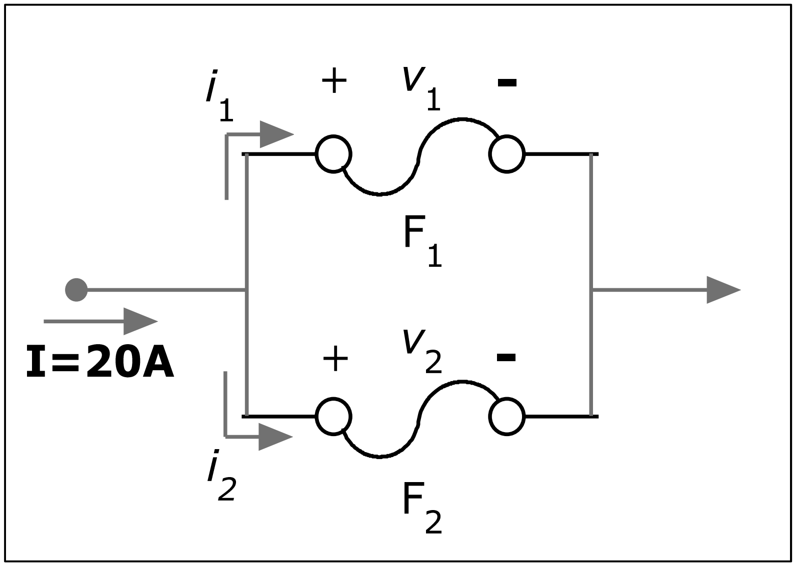


Figure 2

Steady-State

$$v_1 = v_2 \rightarrow i_1 r_1 = i_2 r_2 \rightarrow i_1(0.7)r_1 = i_2(1.3)r_2$$

Solve for i_2

$$i_2 = i_1 \frac{0.7}{1.3}$$

$$i_1 + i_2 = I \rightarrow i_1 + i_1 \frac{0.7}{1.3} = I \rightarrow i_1(1.53) = I$$

$$\boldsymbol{i_1 = \frac{I}{1.53}}$$

$$i_1 = \frac{I}{1.53} = \frac{20A}{1.53} = 13A \ \rightarrow Operating\ Current\ derating\ \frac{13A}{0.75} = 17.42A$$

$$\rightarrow Temperature\ derating\ \frac{17.42A}{0.85} = 20.5A \ \leq fuse\ current\ rating$$

Fuses in Parallel

Example: Two 25A fuse in parallel subjected to a 100,000 cycle square pulse with peak current of 100A for 5ms (Fig. 3)

Square pulse therefore,

$$I^2t = {I_p}^2t$$

$$i_1 = \frac{I}{1.53} = \frac{100}{1.53} = 65.35A \rightarrow {i_1}^2t$$

$$= (65.35)^2(0.005) = 21A^2sec$$

$$100{,}000\ cycle\ derating \rightarrow \frac{21A^2sec}{0.4} = 52.5A^2sec$$

$$Temperture\ derating \rightarrow \frac{52.5A^2sec}{0.85} = 61.7A^2sec$$

$$30\%\ safety\ margin \rightarrow \frac{61.7A^2sec}{0.7} = 88.3A^2sec$$

$$Compare\ {I_p}^2t\ of\ pulse\ with\ {I_f}^2t\ of\ fuse\ at\ 5ms \rightarrow {I_f}^2t \geq {I_p}^2t$$

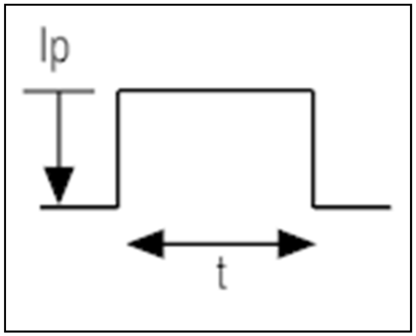


Figure 3

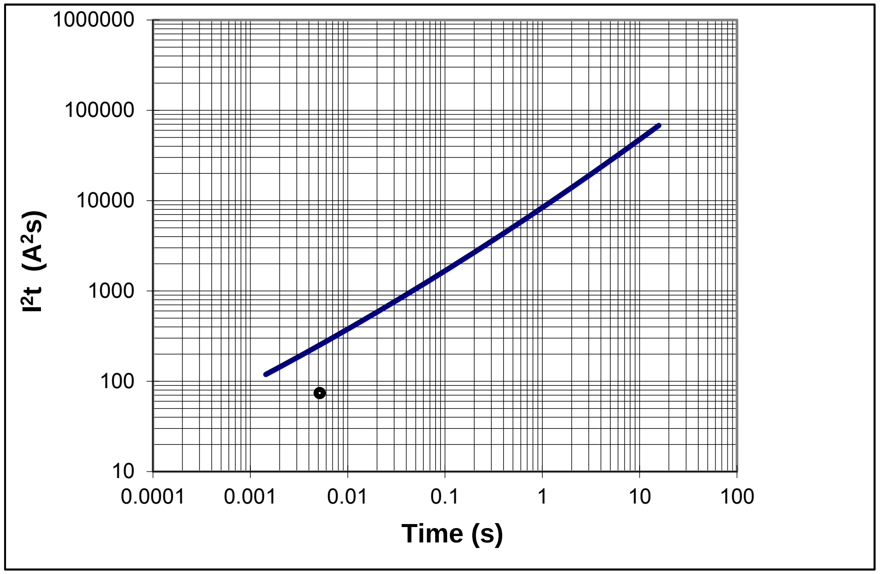


Figure 4

Conclusion

- ***Upper Limit:***
  - *UL or internal safety requirements*
- ***Lower Limit:***
  - *Steady-state requirement (20.5A)*
  - *Transient state (88A^2sec)*