Application of E-Fuse in a DC/DC converter

No Smoke, No Fire
Burnt Units
Want to Avoid

Burnt Motherboards
Common Output Over Voltage Protection Schemes

- PWM controller turns on low side FETs to limit Vout excursion.
- Separate reference and comparator used to trigger output clamp (SCR or interrupting PWM signal to low side driver)
- Separate reference and comparator used to trigger input clamp (SCR crowbars input fuse)
- Input disconnect with latch off feature for over voltage
PWM controlled OV limit

**Pros:**
- Natural feature of PWM controller, provides fast response
- Inexpensive

**Cons:**
- No protection against controller or feedback loop failure
- Relies on input source holding up long enough to blow input fuse
- If fuse doesn’t blow, then no protection on subsequent power on.
Output Clamp (Crowbar)

- **Pros:**
  - Protects against controller and control loop failures
  - Fast response

- **Cons:**
  - If external components added, they must be very large (and expensive)
  - Relies on input source holding up long enough to blow input fuse
Input Clamp (Crowbar)

Pros:
- Protects against controller and control loop failures
- Size of input clamp doesn’t need to be as large as the output clamp

Cons:
- Slow response may not keep output voltage below acceptable limits
- Relies on input current being sufficient to blow input fuse
Input Disconnect (E-fuse)

- **Pros:**
  - Protects against controller and control loop failures
  - Size of disconnect FET is smaller than output clamp
  - Protects against subsequent power on
  - Fast response
  - Input power supply is not a factor

- **Cons:**
  - Disconnect FET is more expensive than a similarly rated fuse
Common Over Current Measurement Techniques
- Low side Rdson sensing
- Inductor sensing
- Input current sense resistor

Common Over Current Protection Schemes
- Fold Back
- Constant current
- Hiccup mode (PWM goes to zero duty and then restarts)
- Tri-state output
- Disconnect input power
Rdson Sensing

- **Pros:**
  - Lossless (no added loss)
  - Inexpensive

- **Cons:**
  - Wide variation over FET vendors, or even lot to lot
  - Variation over temperature
  - Sampled measurement may not accurately represent current delivered to load (e.g. high side MOSFET short)
  - Doesn’t protect against input over current
Inductor Sensing

- **Pros:**
  - Lossless (no added loss)
  - Inexpensive
  - Accurately represents current delivered to load

- **Cons:**
  - Small signal creates signal to noise issues
  - Variation over temperature
  - Doesn’t protect against input over current
Input Current Sense Resistor

- **Pros:**
  - Accurately represents input current
  - No temperature drift
  - Larger signal for increased sensing accuracy

- **Cons:**
  - Added cost
  - Added power loss
  - Doesn’t accurately reflect output current (especially on DC/DC converters with variable output voltages)
Fold Back and Constant Current

- **Pros:**
  - Fault condition recovery without user intervention
  - Easy and inexpensive to implement

- **Cons:**
  - May cause overheating of whatever is causing the fault
Hiccup mode

- **Pros:**
  - Fault condition recovery without user intervention
  - Easy and inexpensive to implement
  - Significantly reduces power delivered to short

- **Cons:**
  - May cause under-voltage ringing on output when PWM goes to zero duty cycle (low side MOSFETs turn on)
Tri-state Output

- **Pros:**
  - Easy and inexpensive to implement
  - Eliminates power delivered to short

- **Cons:**
  - Requires user intervention for recovery
Disconnect Input Power

- **Pros:**
  - Eliminates power delivered to short

- **Cons:**
  - Requires user intervention for recovery
  - May increase cost
An Ideal Solution would protect both the module and the downstream components:

- Eliminate output over voltage
- Fast response to input over current
- Reduced power into output short circuit
- Safe post failure power on
The ideal solution would be an input disconnect (E-fuse) with reset-able latch.

The latch is set for input over current and output over voltage.

Output over current is handled by the PWM.
Actual implementation

- Use N-channel FET for best cost vs. performance
- Include protection diodes to limit gate voltage
- Include ceramic capacitor on input side to reduce voltage spike under heavy load turn off
- Use a charge pump from one of the phases to enhance the disconnect FET
Actual implementation

- Use discrete transistor latch to turn off the disconnect FET if “Latch” is pulled low
- Guaranteed no latch state until Vcc reaches a predetermined value.
- Use open collector signals so various protection mechanisms can be orred together easily.
Actual implementation

- Use 2% zener diode for reference generation
- Least expensive reference for cases where exact over voltage or over current threshold isn’t necessary
- Could easily use a TL431 or similar device
Actual implementation

- Use LM339 to compare Vout to reference voltage
- Hysteresis isn’t needed since when Latch goes low the input disconnect FET is latched off
- Small amount of filtering on Vout for noise immunity, while still allowing fast response
- Vout is the output voltage local on the module, not the remote sense point (in case of open, or shorted remote sense)
Actual implementation

- Sense input current across input fuse or sense resistor
- Create proportional current through a resistor to ground (R6)
- Compare the voltage developed across R6 to the reference
- Filter the signal only as much as necessary for noise immunity, to guarantee fast response
1 Unit was wired up to test a multiphase converter for the case of a high side MOSFET short

- Test setup consisted of:
  - 4 phases
  - 300kHz switching per phase
  - 1.3V Vout (no load voltage, unit has AVP)
  - 12V Vin
  - One high side FET was wired for normal gate pulses, or +20V
  - Shorted high side FET while running
12Vin, 1.3Vout, 110A load induced high side FET short

- Ch1 offset by 1V = Vout
- Ch2 = current sense signal
- Ch3 = VIN_F (12V fused)
- Ch4 = VDG (gate of FET)
12Vin, 1.3Vout, 0A load induced high side FET short

- Ch1 offset by 1V = Vout
- Ch2 = current sense signal
- Ch3 = VIN_F (12V fused)
- Ch4 = VDG (gate of FET)
Some interesting results from this test:

- At high load the load and PWM overcome the high side FET short and the output voltage doesn’t rise.
- At no load the PWM can’t overcome the high side FET short and the output voltage does rise.
- In both cases, even with the trip threshold set at 3x the normal input current, the input over current circuit tripped the latch before the output voltage rose to the OVP limit, and before the fuses opened.
Why input current limit and not just a fuse

- Not all systems have enough current capability to blow a fuse
- Fuses take a long time to blow (10ms to many seconds) and an output over voltage may still occur
- Some components may draw large surge current and emit smoke without drawing enough sustained current to blow a fuse (e.g. ceramic capacitors)
Ch1 = Vout  Ch2 = remote sense+

Comparing speed of over voltage detection and response of SCR crowbar (left) to input disconnect (right) when shorting remote sense

- Both converters have OVP threshold of 2V
- Both were run with a minimal load of 5A
Final Notes

- Input disconnect FET eliminates catastrophic over voltage on the output of a converter.

- Including input over current detection adds additional protection for systems with less current capability than needed to open a fuse.

- Input over current detection is faster than a fuse and will respond to very short pulses of high current (as may be present in failed ceramic capacitors or high side FETs).
- Discrete implementation is inexpensive but space consumptive
- High side current monitors are available in one small package
- Disconnect FET latch, OVP, OCP and charge pump may all be integrated into one IC.
  - The problem becomes finding the IC with the needed features and not too many expensive extras