A Radiation-Hardened Quad Power Switch with Fuse-Like Fault Shedding Characteristic

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Agenda

- Introduction
- Fuse-type load shedding characteristics
- An integrated RLCL with fuse-type characteristics
- Applications
- Circuit characteristics during radiation tests
- Conclusions and future work

Introduction

- **Need for load protection in space applications**
  - Importance of protecting all types of loads
  - Traditional use of Latching Current Limiters (LCL) and Re-triggerable LCL (RLCL)
- **Challenges with loads featuring large and long inrush currents**
  - Issues with regular LCLs for heavy load start-up
  - Setting trip current levels
    - Derating peak load inrush current
    - Trip time considerations
- **Effectiveness of protection**
  - Normal operating conditions vs. fault currents
  - Energy dissipation concerns

Issues with Regular Latching Current Limiters

- **Need for load protection in space applications**
- **Challenges with subsystems having large inrush currents**
- **Effectiveness of protection**
- **Limitations of regular LCLs**
  - Fixed current and trip time settings
  - Need for derating current limit based on peak load inrush current
  - Can stress wire and other circuit elements integrity / fusing

Traditional Load Protection Methods

- **Space-qualified fuses and relays**
  - Used in power distribution across satellite subsystems
  - Inexpensive, small and light
  - Reliability can limit the application
  - Accuracy is not great

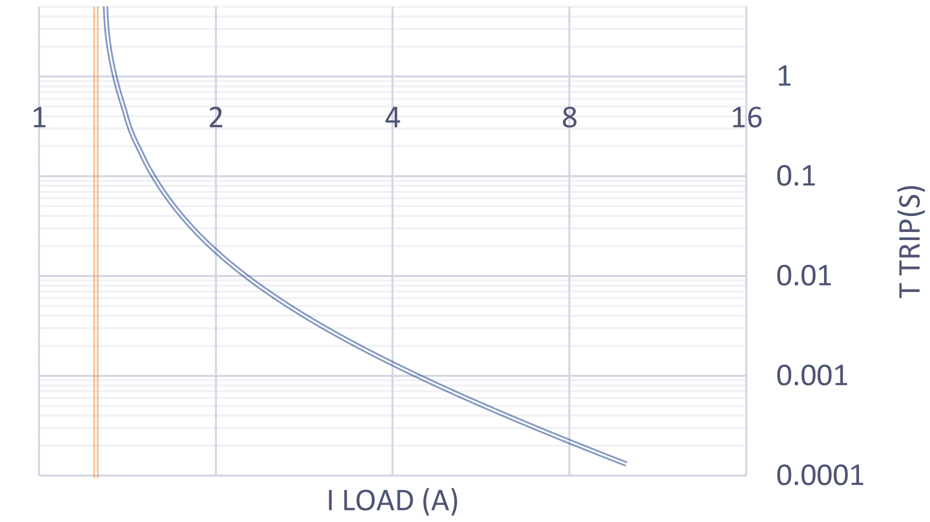
➢ **One reliable alternative is**

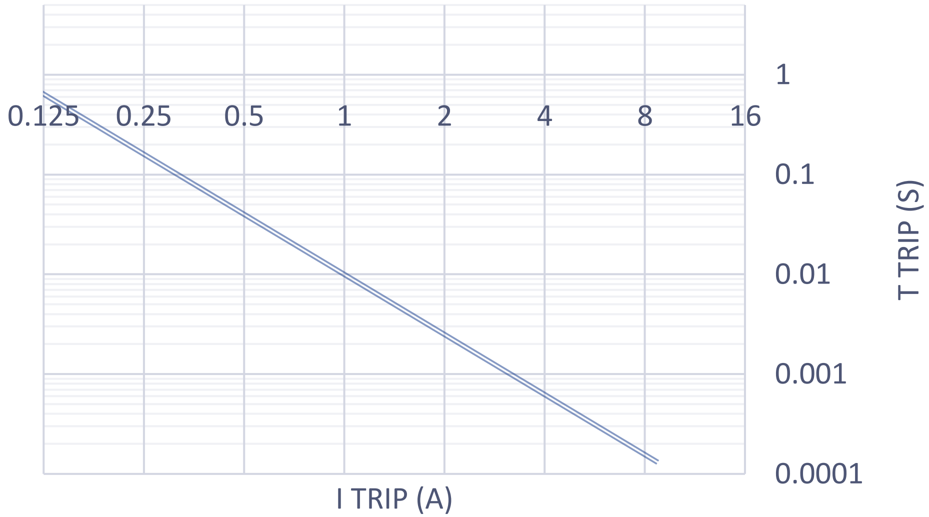
an electronic LCL / RLCL with adaptive trip time

Characteristics of Fuse-Type Load Shedding

- **The physical mechanism is based on self heating up to melting temperature due to dissipated power**
  - In a fixed thermal environment, the trip (melting) time is inversely proportional to the dissipated power
  - For a resistive circuit $t \sim 1/i^2$ so $i^2 t$ = constant
- **For a fixed load current**
  - If current is larger than the rated current:

    $I_{fault} = I_{load} - I_{rated}$
  - The trip time is: $t_{trip} = K/I_{fault}^2$
- **If current is variable** $\int_0^{t_{trip}} i_{fault}^2(t)dt = K$





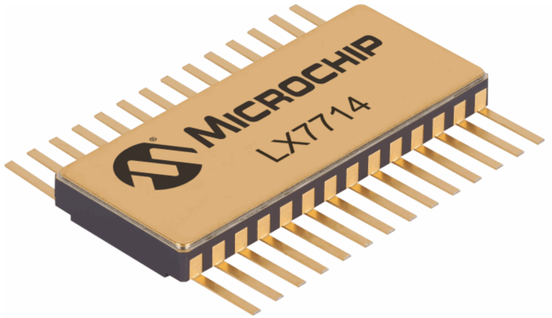
Energy Dissipation in Fault Conditions

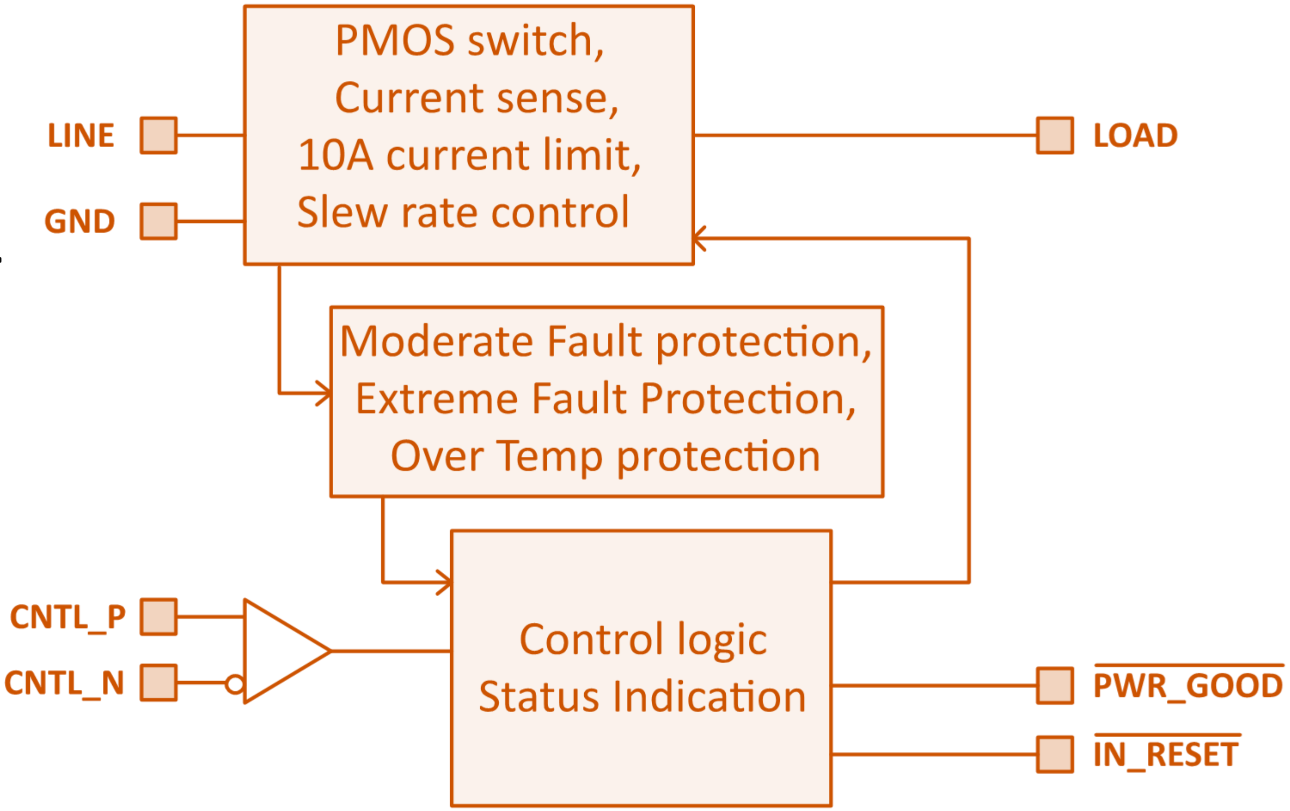
- **Trip time definition**
  - Defined by implicit equation if current is not constant
- **Energy dissipation in load**
  - Total energy dissipated due to fault current is constant
  - Maximum energy dissipated in conductor or windings
- **Examples of loads with large inrush currents**
  - Loads with resistive and inductive components
  - Heaters, relays, motor drives
- **Efficient protection**
  - Fuse-like trip characteristic required

Design and Implementation

LX7714 Quad Resettable E-Fuse

- Internal 2.5A or 1.25A maximum rated power switch
- Switches four independent voltages in the range 14V to 46V
- Handles 10A or 5A peak currents per switch safely
- Switch resistance is 250mΩ (typ.) or 500mΩ (max.)
- Internal output voltage rise time control
- Differential TTL input on/off control
- Power On, Off and Hiccup mode status





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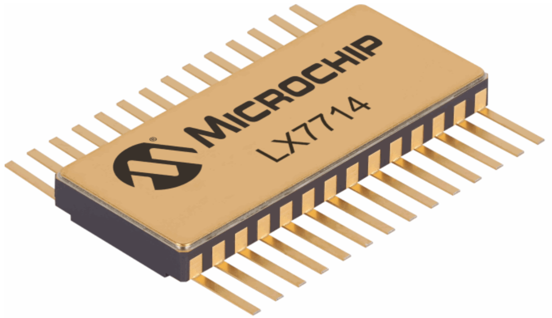
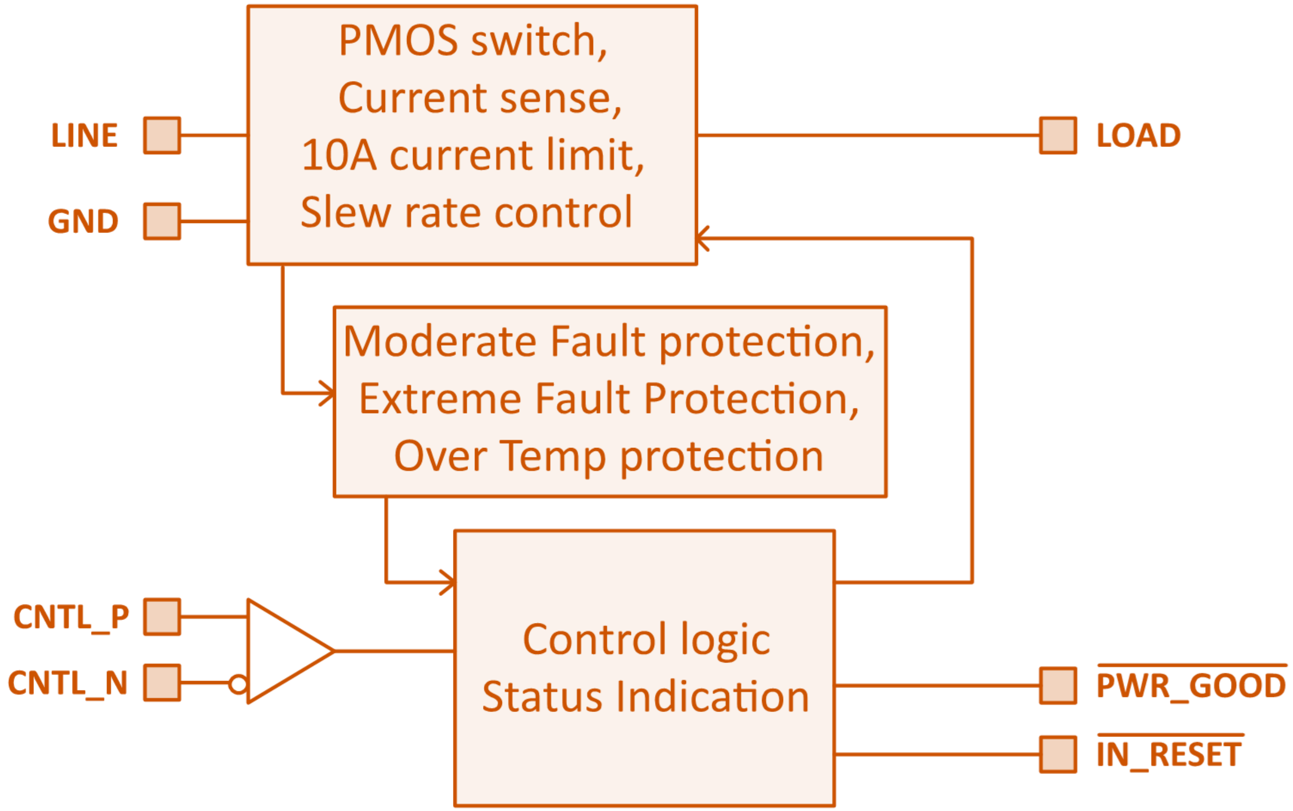
Design and Implementation (cont.)

LX7714 Quad Resettable E-Fuse



- Hiccup mode for automatic fault handling
  - 10 second load removal on fault detection, 4096 retries
- Thermal shutdown for secondary protection
- Low resistance DIP power package
- Single event immunity
- Radiation Tolerant: 100 krad TID, 50k ELDRS, SEE immune
- 28-pin hermetic ceramic flatpack
- Pre-production samples available with evaluation board



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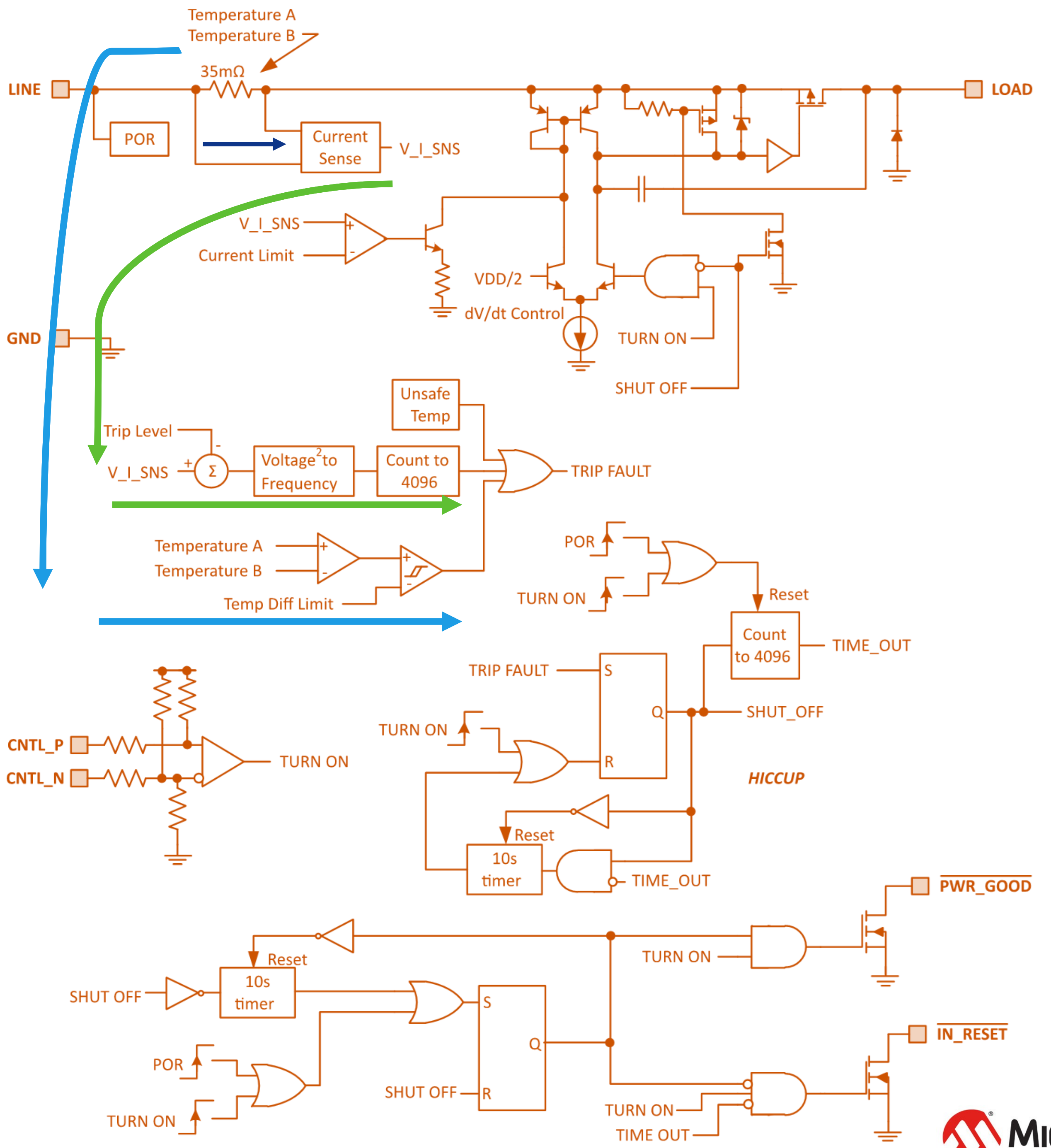
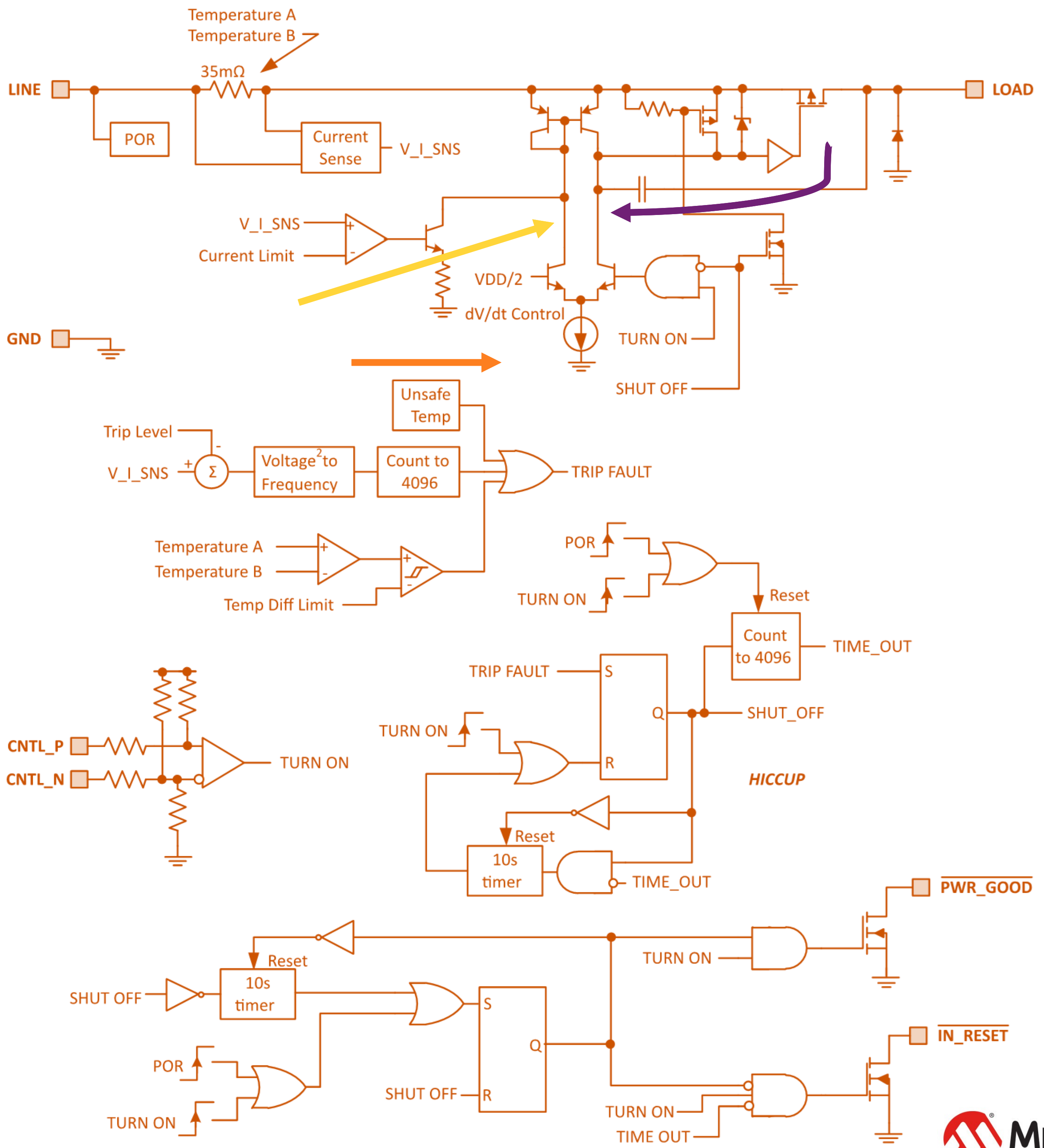
Functional Diagram

- **Fuse-like characteristic**
  - **Line/Load current is amplified, limit is subtracted, resulting value is squared and integrated using a VCO + counter**
  - **Secondary faster protection for heavy load based on junction temperature difference between the sense element proximity and away as propagated**
    - Equivalent to a limit on dissipated energy



Other Protection Mechanisms

- **Comprehensive Protections for Channels**
  - Guarantees protection of both load and protecting device
  - **Implements turn on/off slew rate control**
  - **Current limit set at around 10A**
  - **Maximum junction temperature protection set at more than 150°C with some hysteresis**



Trip Condition and Restart Mechanism

- **Trip condition**

$$\int_0^{t_{trip}} i_{fault}^2(t)dt = K \begin{cases} V_{i_{sns}} = a_1 i_{sns}\ ; \\ f_{VCO} = a_2\left(V_{i_{sns}} - V_{trip}\right)^2;\ \ t_{trip} = {}^{N}\!\big/_{a_2 a_1^2 i_{fault}^2} \implies K = {}^{N}\!\big/_{a_2 a_1^2} \\ t_{trip} = \dfrac{N}{f_{vco}} \end{cases}$$

- **Control of rated current**
  - V_{trip} offset controls the rated current
  - K is controlled by changing the VCO gain a_2
- **Channel restart timing**
  - Restart timed by a longer timer
  - Allows load and MOSFETs to cool down (duty cycle during fault / retry condition)
- **Maximum number of retries**
  - Avoids unnecessary retries to prevent load fault condition

Secondary Protection Details

- **Implementation of secondary protection**
  - Limits maximum instantaneous power dissipated in sense resistor and nearby power MOSFET
  - Uses a limit comparator for junction temperature differences
- **Temperature difference and power dissipation**
  - Developed on die thermal resistance
  - Proportional to power dissipated in resistor and MOSFET
  - Reproductible and radiation hard since it is based on fundamental heat propagation physics and material constants of the substrate
- **Safe operating region**
  - Turning off the device at a limit value for the temperature difference sets a limit for resistor and MOSFET safe operation below maximum power

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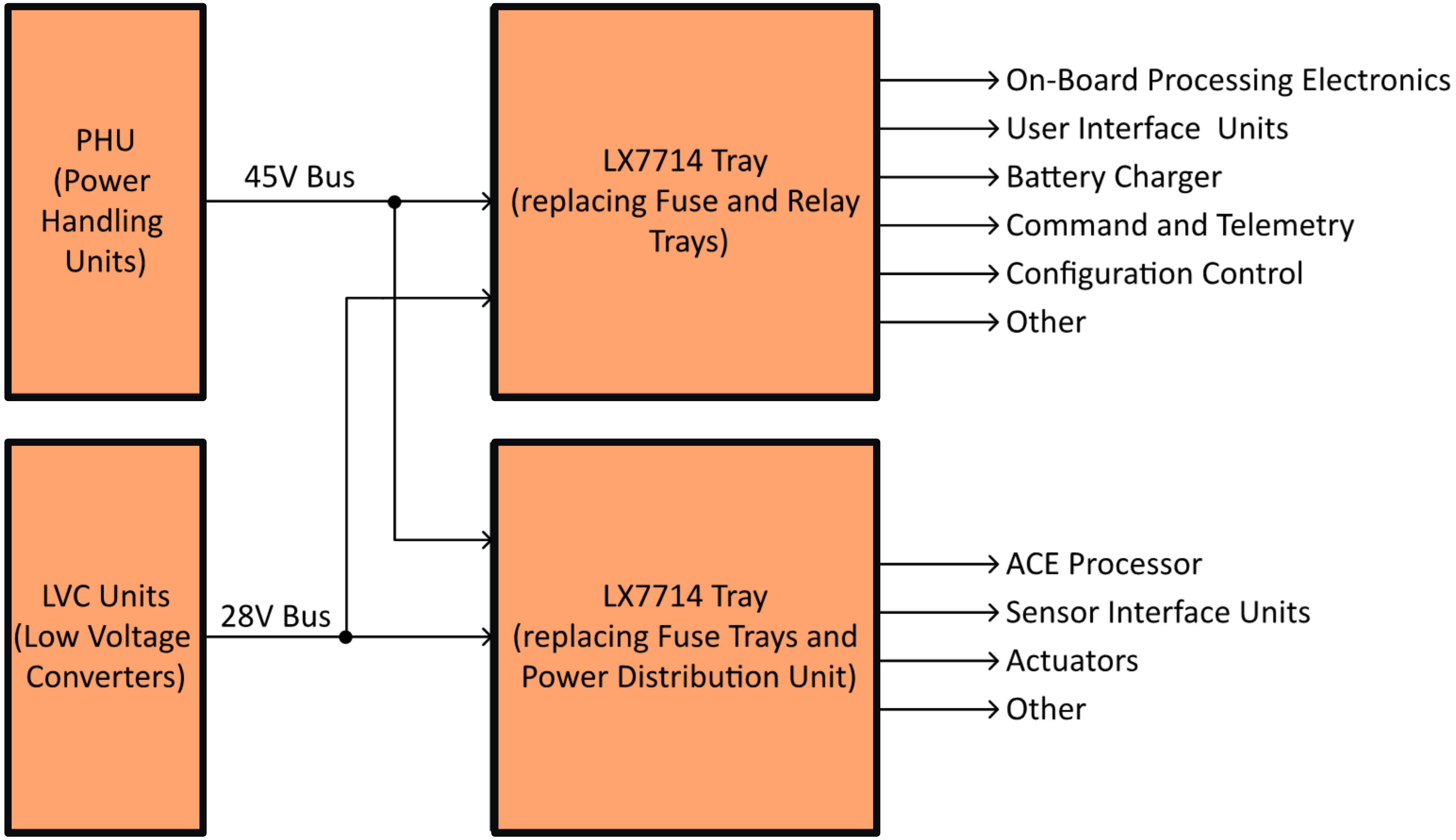
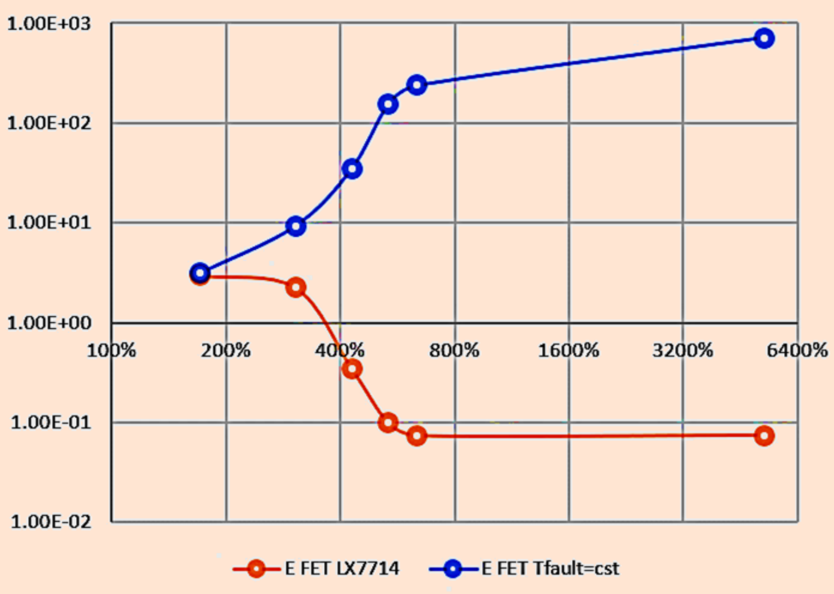
Typical System Application

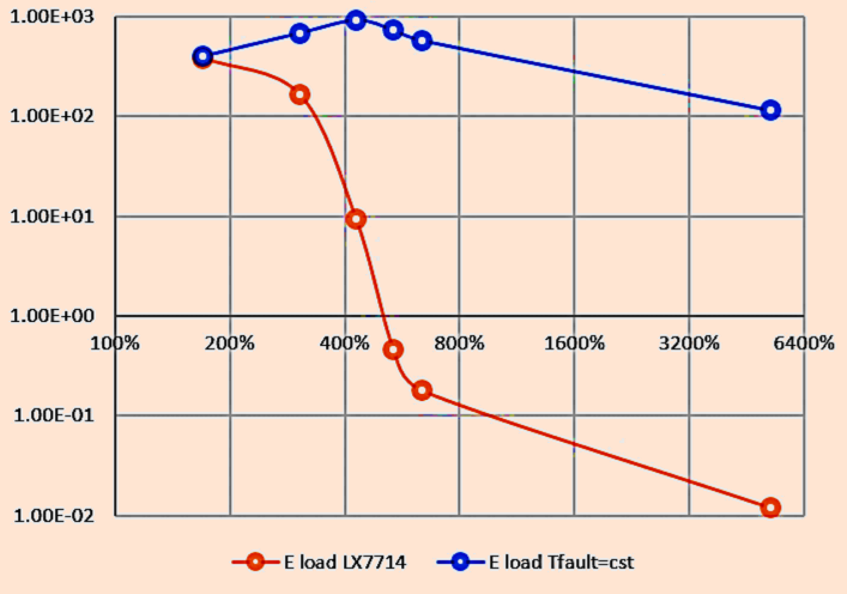
- Substitutes fuse and relay trays
- Used in satellite power distribution



Comparison with Classical RLCL

- **Comparison Setup**
  - Two applications sized similarly to the condition described in the introduction
  - Measured data from LX7714 compared to calculated data representing classical RLCL

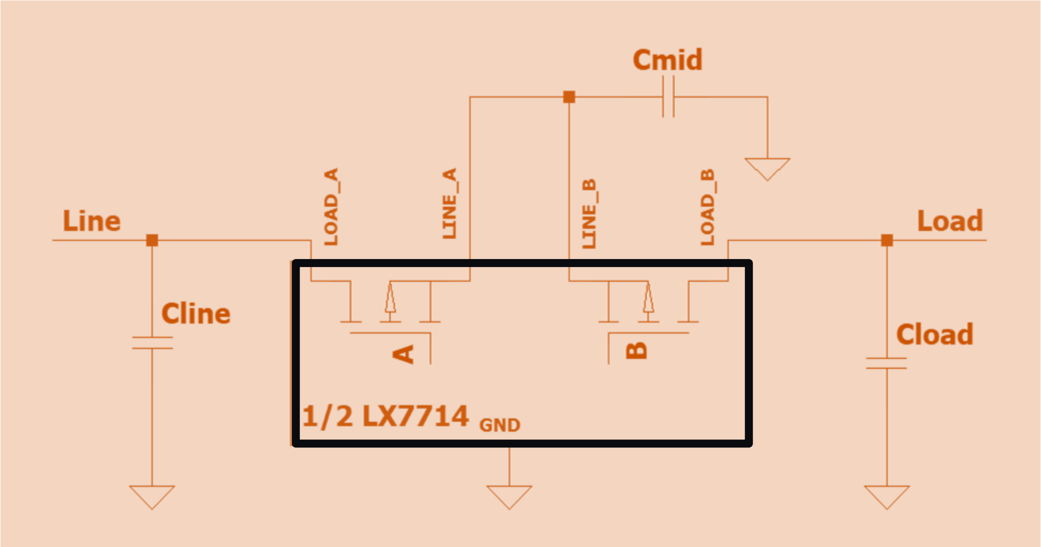




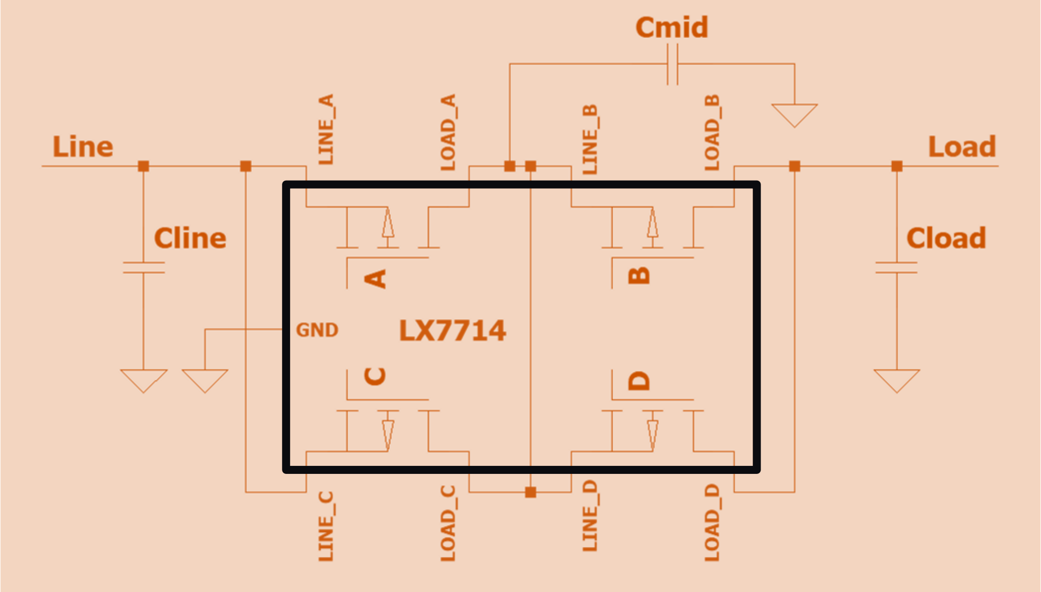
- **RLCL MOSFET Perspective**
  - Medium advantage for LX7714 on medium overload condition
  - four orders of magnitude advantage for LX7714 in heavy overload
- **Load Circuit Dissipated Energy**
  - Medium advantage for LX7714 on medium overload condition
  - four orders of magnitude advantage for LX7714 in heavy overload

Other Applications with Multiple Channels

- **Bidirectional isolation switches**
  - Useful to isolate line and load circuits in both directions
  - Both switches are controlled using the same on/off signal



- **Redundant fault tolerant switch**
  - Uses all four switches from one LX7714 package
  - Normally A and B are both controlled with the same on/off signal and C and D are off / cold spared
    - If any of A or B fail open, the parallel devices C or D are turned on
    - If any of A and B fail short, load can still be shut down by the still OK switch



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Radiation Test Results Overview

Parameter	Min.	Typ.	Max.	Pre TID	Post 100 krad	Units
Switch voltage-drop			250	146 … 153	150 … 157	mV
Load voltage in off state	0		500	41 … 42	45 … 69	mV
Turn-off delay			150	17.4 … 18.3	12.8 … 16.4	µs
Turn-on delay			100	28.5 … 28.8	29.4 … 34.4	µs
Rising load slew rate	1	2.5	4	2.80 … 2.95	2.59 … 4.0	V/µs
Falling load slew rate	-4	2.5	-1	-2.86 … -2.69	-4.24 … -2.8	V/µs
Load current limit	7.5		12.5	8.7 … 8.9	8.6 … 8.9	A
Trip current	2.5		3.5	2.93 … 3	2.92 … 3.02	A
Overload trip time	0.5	1.5	2.5	1.95 … 2.48	2.14 … 2.74	s

- **Switch voltage drop**
  - Small shift after irradiation
- **Load voltage**
  - Increases by less than 30 mV when switch is off and floating
- **Turn-on delay**
  - Increased by 1 to 7µs
- **Turn off delay**
  - Decreased by 1 to 5µs
- **Trip current**
  - Changes by less than 1%
- **Overload trip time**
  - System level performance

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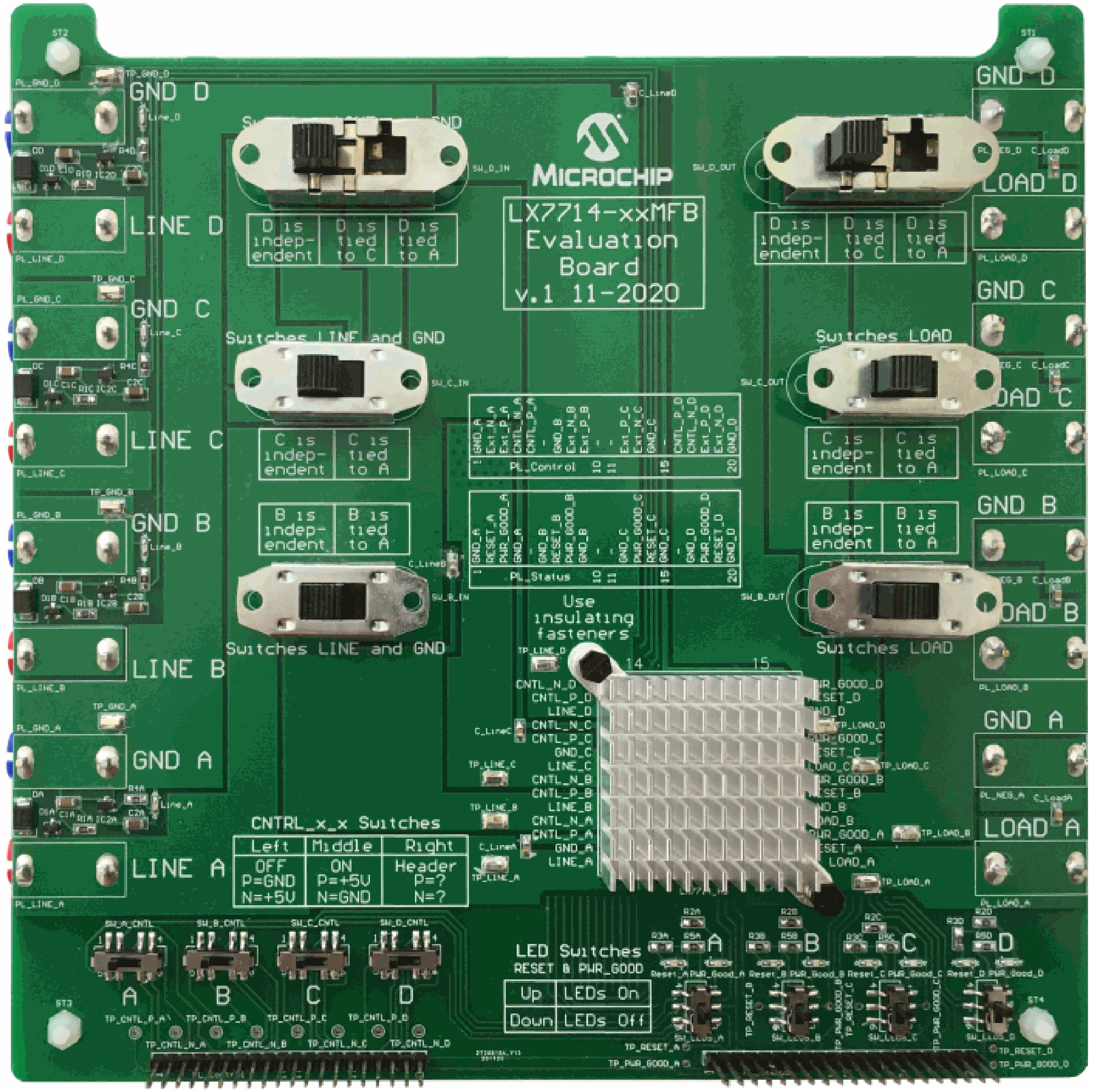
Support Tools for LX7714



LX7714 Evaluation Board

- Supports ZIF socket or directly soldered LX7714
- Switches and status LEDs simplify standalone operation
- Power switches allow for easy channel customization

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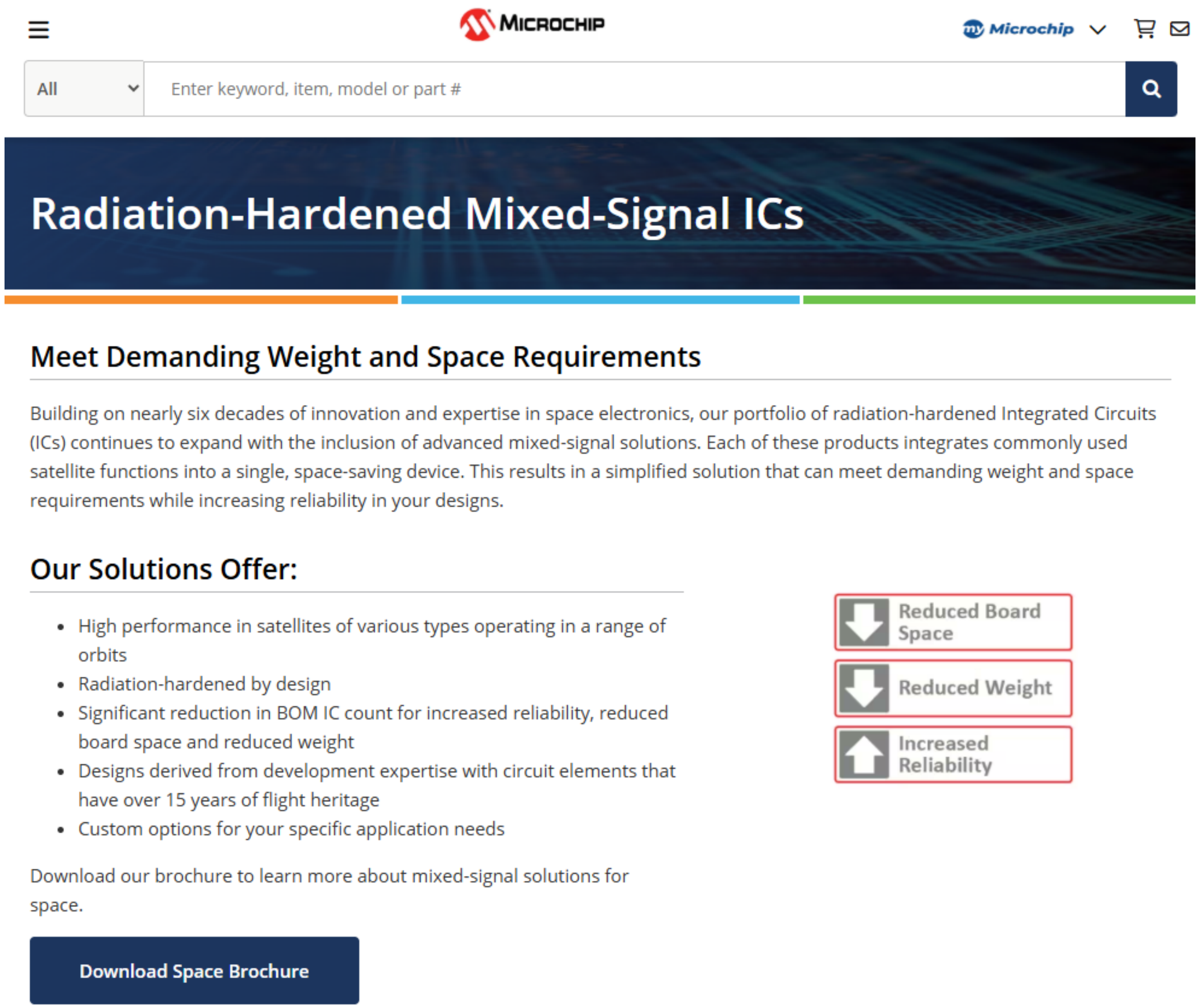
Conclusions and Future Work

- **Integrated RLCL implementation**
  - Fuse-like load shedding characteristics
  - Natural fit with safe operating area for pass transistor

- **Advantages of protection scheme**
  - Better solution compared to traditional LCL/RLCL
  - Effective for loads with large or long in-rush currents

- **Possible future developments**
  - Identify other types of load shedding that are useful for current space electronics



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