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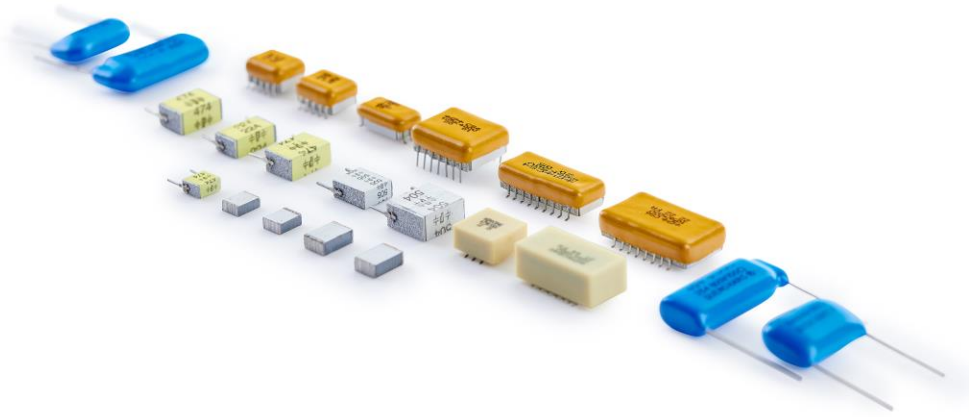
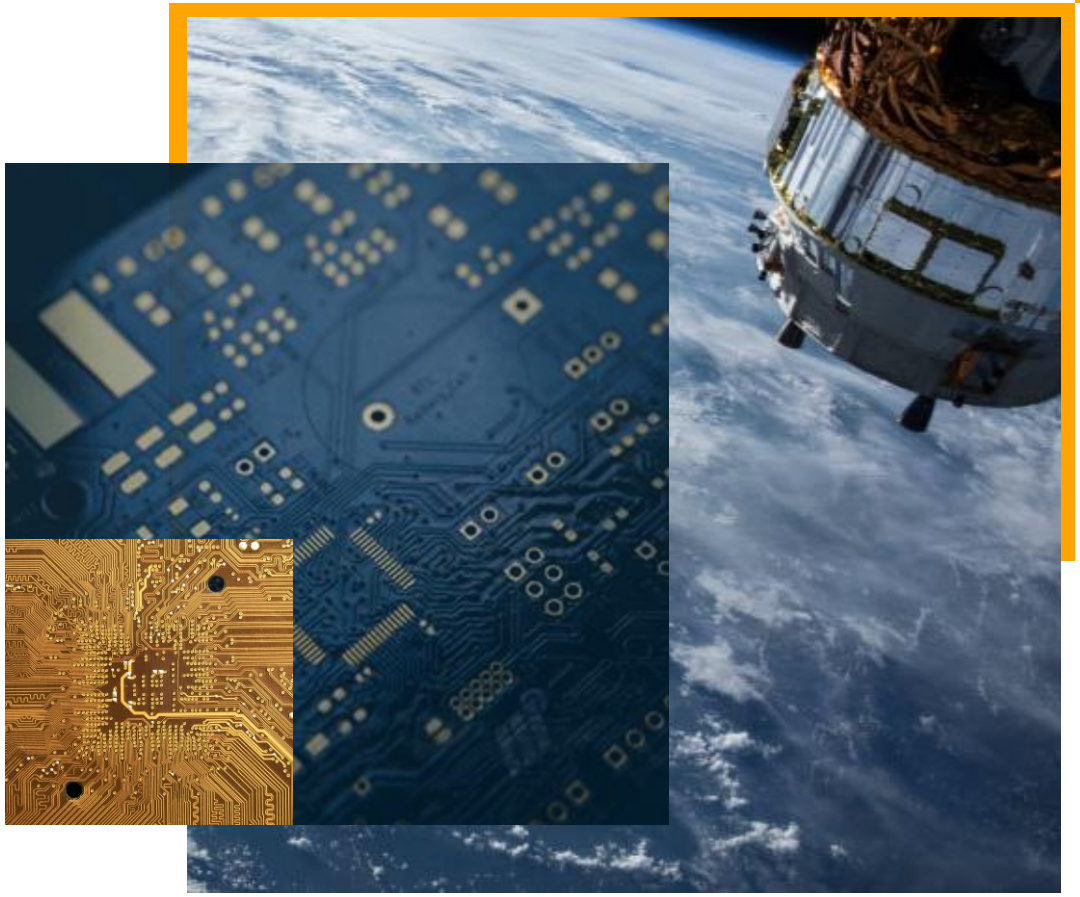




CMSE 2023 Technical Session: Inherently Robust Film Capacitor Solutions for Embedded Power Applications in Military and Space

Zach Kilsmith
Director of Engineering

Zach Kilsmith

- Director of Engineering for Quantic Paktron.
- B.S. degree in Mechanical Engineering from Worcester Polytechnic Institute in central Massachusetts where I still reside.
- After graduation I spent several years working as an applications engineer for switch-mode power supply manufacturers
- In 2017 I joined Quantic Paktron.
- In my off-time I enjoy spending time with my wonderful wife and children and tinkering with things of all sorts.

Making the Argument: Why *should* COTS film capacitors be considered for mission-critical applications?

Military Specification	Generic Designator	Description	Additional Notes
MIL-PRF-83421	CRH	Fixed, Metallized Plastic Film	Axially leaded, hermetically sealed, polypropylene and PPS dielectric options
MIL-PRF-87217	CHS	Fixed, Supermetallized Plastic Film (OBSOLETE)	No active manufacturers for CHS as of 2023

NASA Parts Selection list also references the above

This is not a cost-based argument, it is all about performance!

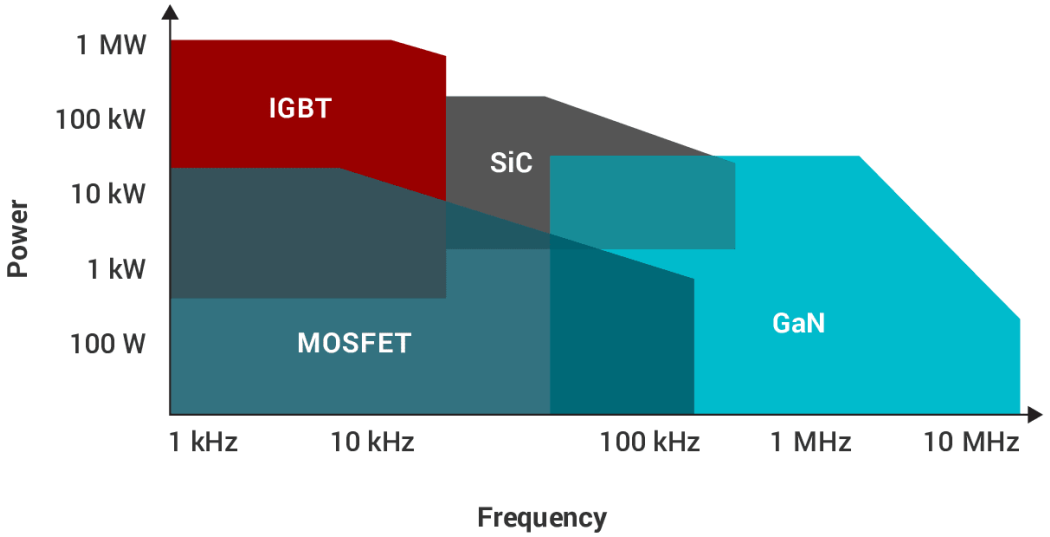
Disadvantages of MIL-PRF-83421

- Specifies only axially leaded capacitors (no DIP, SMD, CHIP)
- Must be hermetically sealed to meet standard
- Max operating voltage specified to 400VDC
- Max available temperature of 125C (with derating)
  Only available dielectric for 125C is PPS, not self-healing

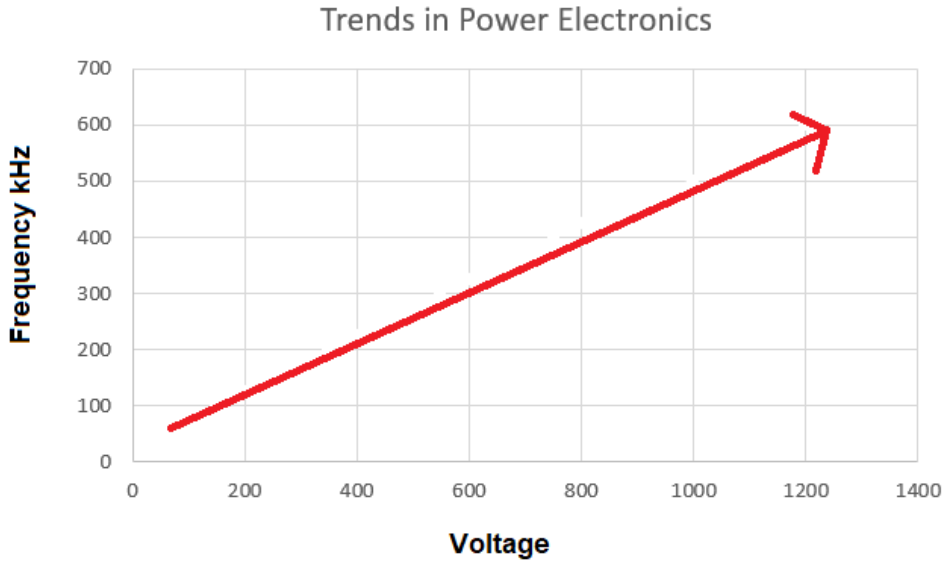
MIL-PRF083421 "CRH" style capacitor with 1984 date code
source of photograph https://www.ebay.com/itm/184461245894

Trends in High Reliability Power Electronics

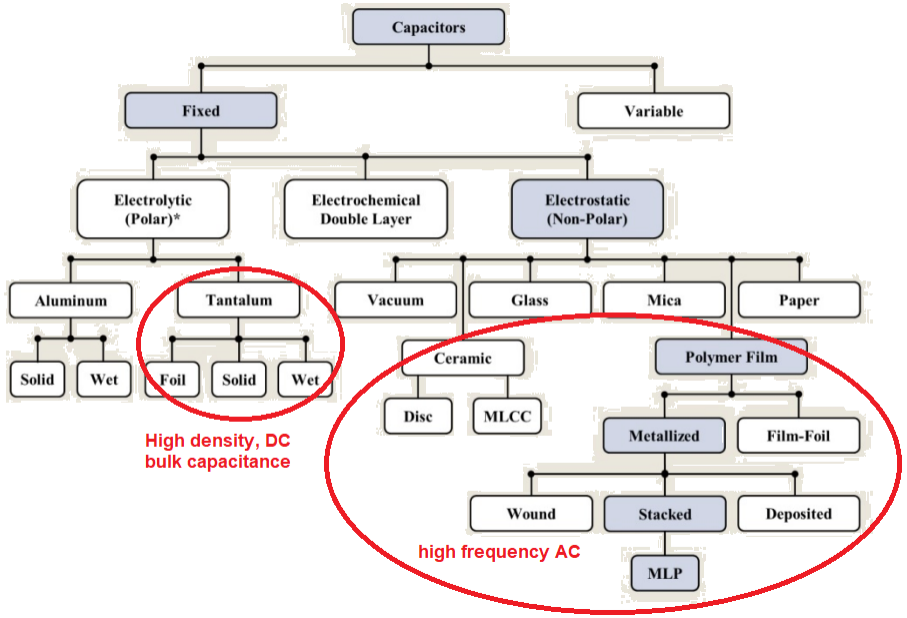
Higher frequency: smaller magnetics, less weight (SWaP)
GaN, SiC can have better rad stability and efficiency over Si
gate drive voltage and frequency domain must be considered



source https://www.ti.com/technologies/gallium-nitride.html

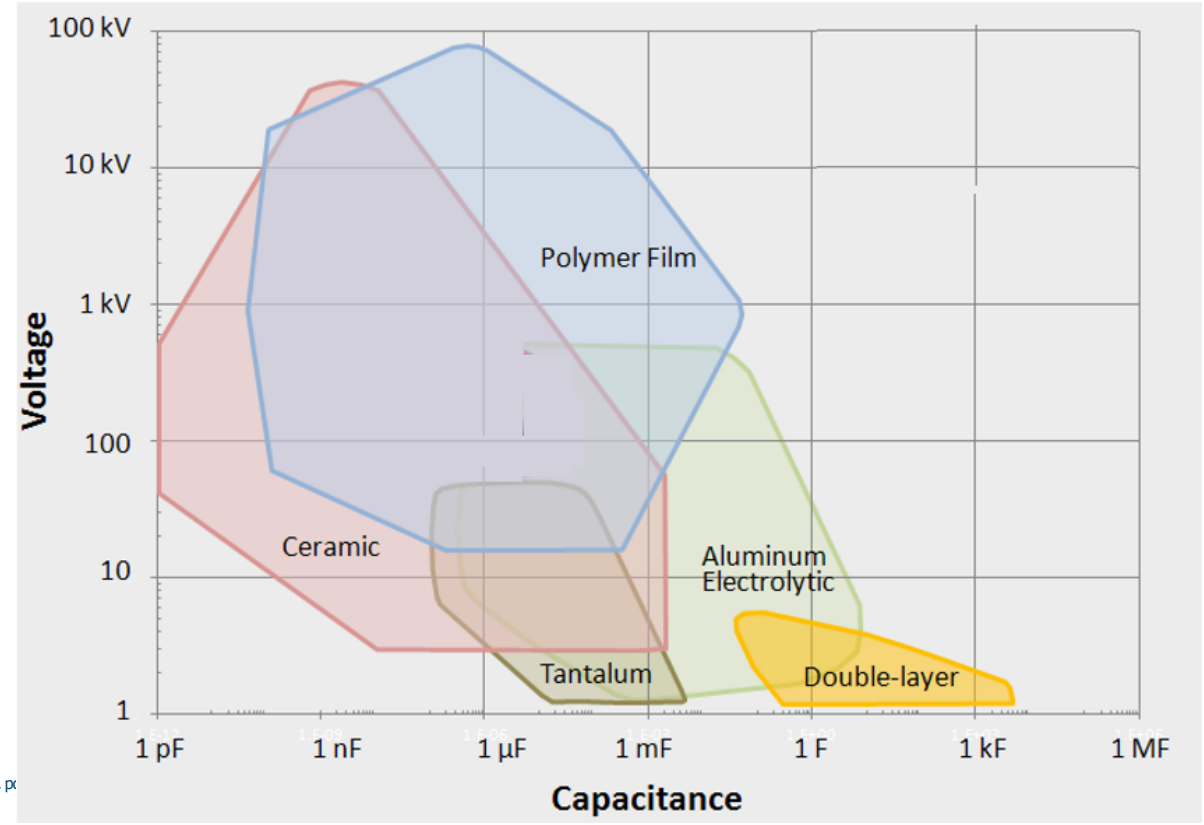


Are There Mil-Spec Alternatives to MIL-PRF-83421 Film Capacitors?



Capacitor Family Tree

Source https://d2f6h2rm95zg9t.cloudfront.net/94541529/whitepaper_Polymer_Film_Capacitors_Provide_Needed_Performance_44289368.p



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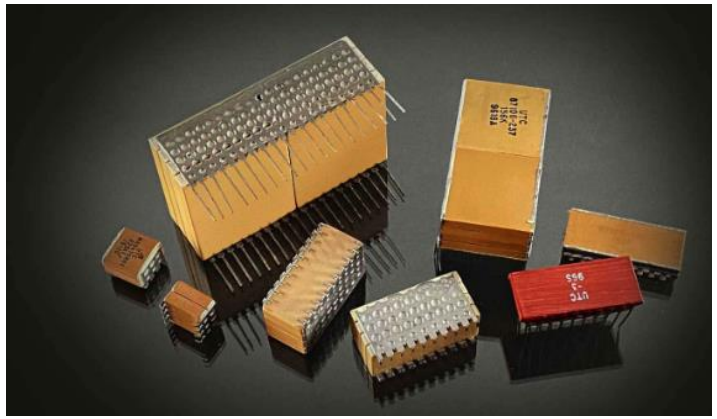


Mil-PRF-49470 style ceramic capacitors
source of photograph https://www.quanticutc.com/categories/military

Multilayer Ceramics have displaced film capacitors in many military, space and mission critical applications in recent years, but there are limitations to MLCC technology

Military Specification	Generic Designator	Description
MIL-PRF-20	CCR	Fixed, Ceramic, Temperature Compensating, Established Reliability Radial Lead or Axial Lead
MIL-PRF-123	CKS	Fixed, Ceramic, **Space Level** Radial Lead, Axial Lead, Chip or DIP
MIL-PRF-39014	CKR	Fixed, Ceramic, Established Reliability Radial Lead, Axial Lead or DIP
MIL-PRF-55681	CDR	Fixed, Ceramic, Chip, Established Reliability
MIL-PRF-49467	HV	Fixed, Ceramic, Multilayer, High Voltage, General Purpose
MIL-PRF-49470	PS	Fixed, Ceramic Dielectric, Switch Mode Power Supply Stacked Chips with Lead Frames for Level 2 Applications
DSCC-DWG-87106	---	Fixed, Ceramic, Switch Mode Power Supply Stacked Chips with Lead Frames for Level 3 Applications

Source: https://nepp.nasa.gov/npsl/Capacitors/Cer_type.htm

Ceramic Capacitors: Advantages and disadvantages

Advantages

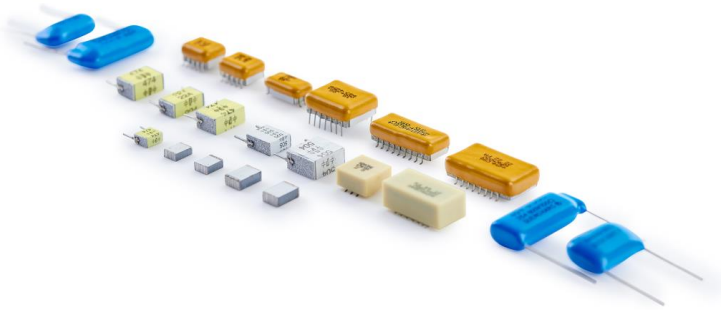
- Vast selection of mechanical footprints, styles, terminations
- Vast selection of voltage ratings, capacitance values
- Very high power density (for electrostatic type, high frequency domain)
- Wide selection of dielectric substrate allows for optimal choosing of dielectric constant (K), temperature coefficient, and Q factor (D.F.) depending on application
    - Example X7R Vs. C0G
    -
- Ultra High temperature ratings 200C +

Disadvantages

- Mechanically brittle, prone to cracking
    - Cracking can be caused by temperature shock, handling during manufacturing, reflow soldering
    - High amplitude voltage can cause a piezo effect which leads to cracking
- Short – mode failure
    - Cracking leads to failure, which is generally short mode, can cause burning or arcing in low impedance applications
- DC Bias effect on capacitance (substrate dependent)
- Use based aging, metal migration, temperature coefficient can be significant (depending on substrate and electrode type)

Multilayer Polymer Capacitor: A Stable, Robust Alternative to MLCC

Angstor® Capacitor • Capstick® Capacitor



SMD Leadframe and EIA chip styles available
X7R or C0G "like" electrical properties depending on film

Voltage Range

50-500VDC
630-1200VDC (Pending)

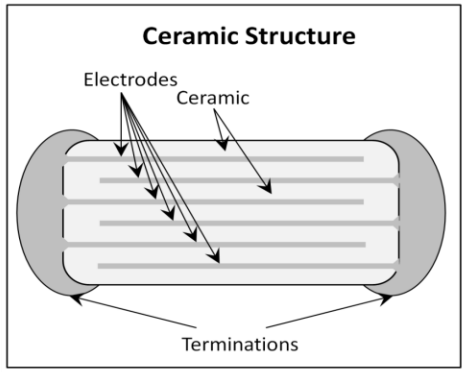
Cap Range

.1uF to 20uF standard

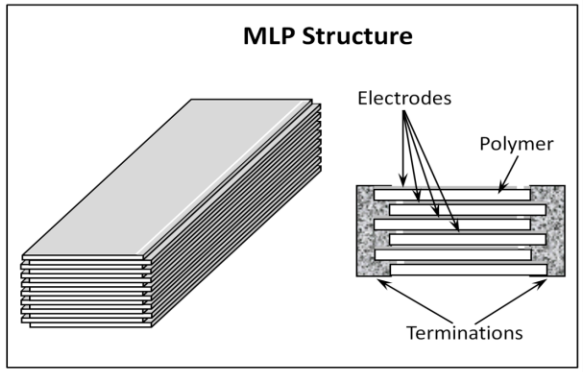
- **Highest ripple current** x C*V ratings in the industry
- Ultra low D.F,
- **Self-Healing** capability, open failure mode
- CTE Match to FR4
- -55C to +150C operating temperature range
- Ultra low ESR/ESL
- **Low Mass** <25% of equivalent MLCC
- Low losses at high frequency
- Excellent for resonant circuits
- High dv/dt
- Efficient size
- Rugged construction
- Automotive AEC-Q200 (Pending)
- **Made in U.S.A.**

Design Advantages

Multilayer Polymer (MLP) Capacitors are structurally similar to MLCC



MLC – Multi-Layer Ceramic



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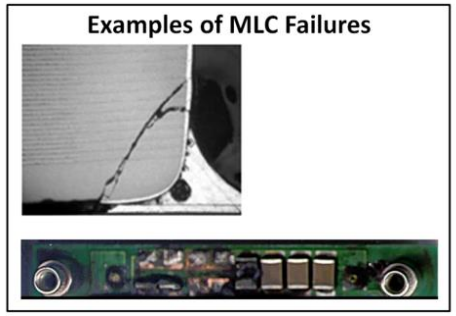
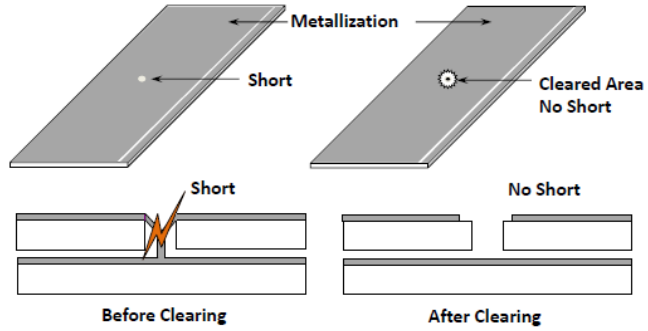
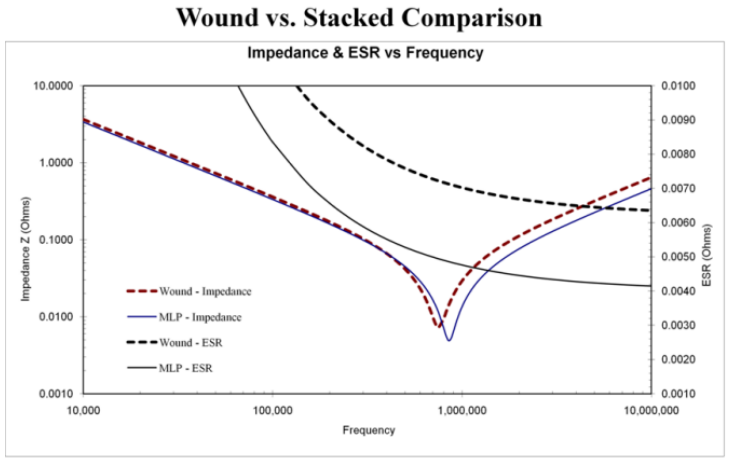


Advantages of MLP

- High frequency, lower ESL/ESR due to mechanical structure
- Self-healing, mechanically robust design due to polymer film construction
- Lightweight <25% of equivalent ceramic

Self-Healing





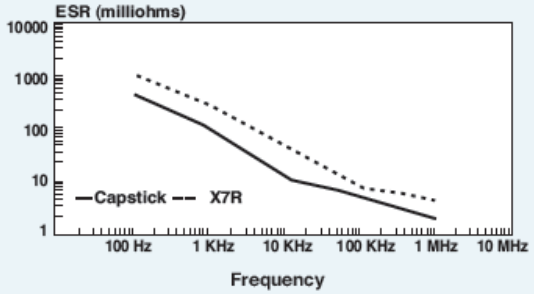
Comparison of X7R Vs polyester base MLP technology

Multilayer Polymer Film (MLP)	X7R Ceramic (MLC)
✔ Stable under voltage	Cap drops 40% at 100 volts bias
✔ Stable under AC voltage	DF increases with AC voltage
✔ Chip is plastic with good TCE	Body is ceramic which cracks
✔ Stable over temperature	DF increases at low temperature
✔ No aging mechanism	Cap drops per decade hour
✔ Resilient under thermal shock	Ceramic body cracks easily
✔ Self-clearing thin electrodes	Thick film electrodes fail short
✔ Stable under mechanical stress	Piezoelectric voltage sensitive
✔ Ultra Low ESR	Low ESR
✔ Dissipation Factor ≤ 1%	Dissipation Factor ≤ 2.5%

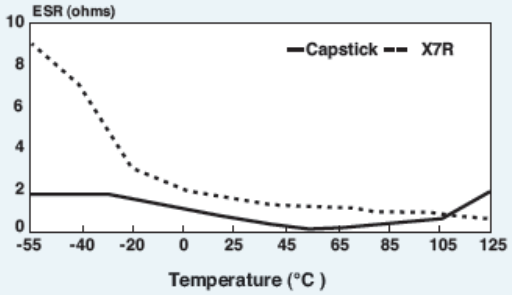
TYPICAL CHARACTERISTICS

The following graphs contrast important characteristics of MLP Capsticks to MLC ceramic units in typical, dynamic converter conditions. The electrical stability of the MLP capacitor is clear.

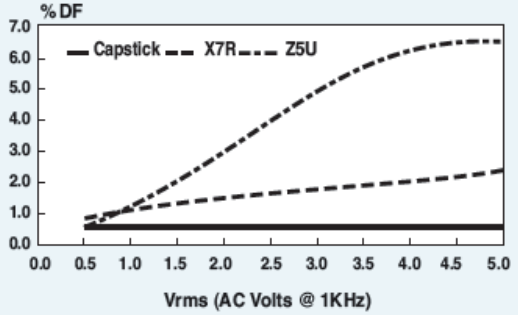
ESR vs. Frequency



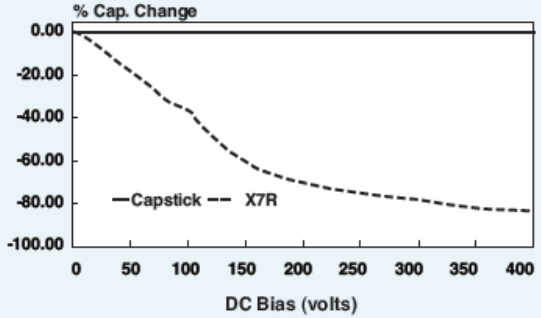
120 Hz ESR vs. Temperature



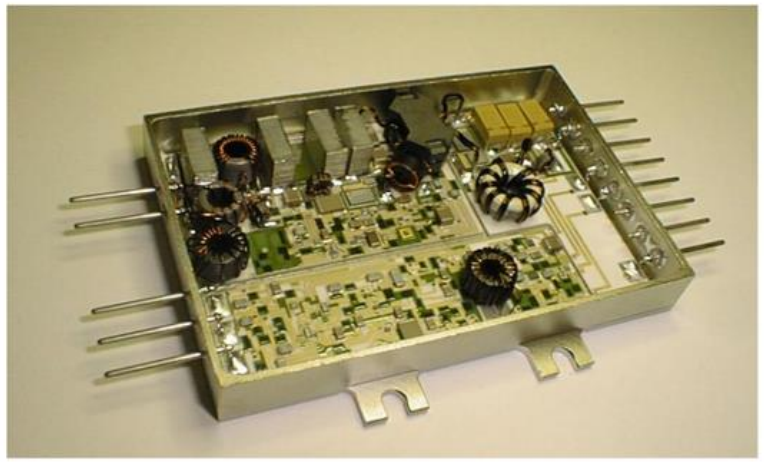
Dissipation Factor vs Vrms



Capacitance vs DC Bias



Space and Military Heritage



- MRO: 2005
- Space Shuttle Discovery OMM 2002
- LEO, small sat heritage
- Extensive use in Tier 2 airborne military embedded power supplies
- Used on FADEC Platforms

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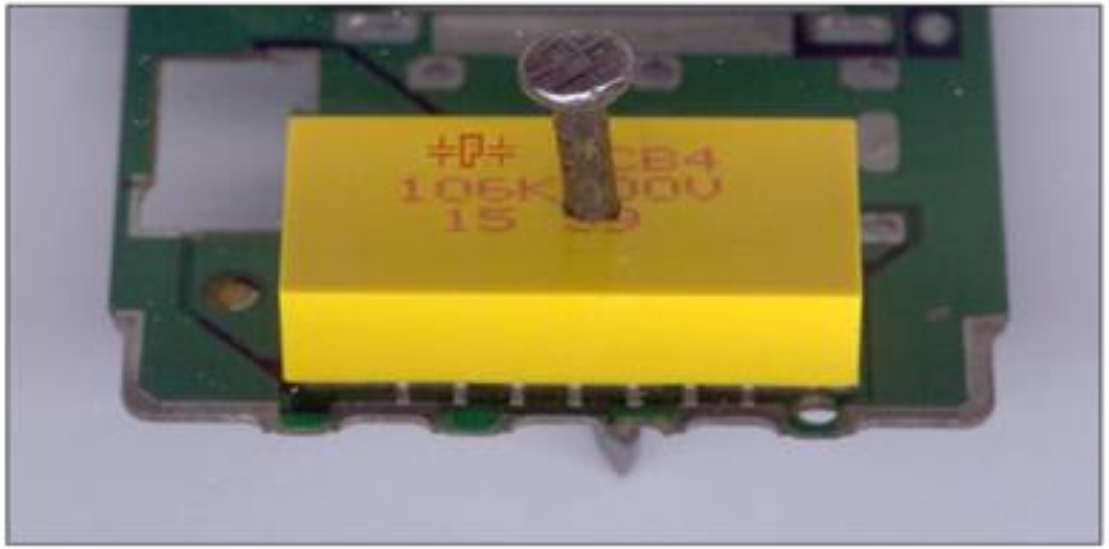
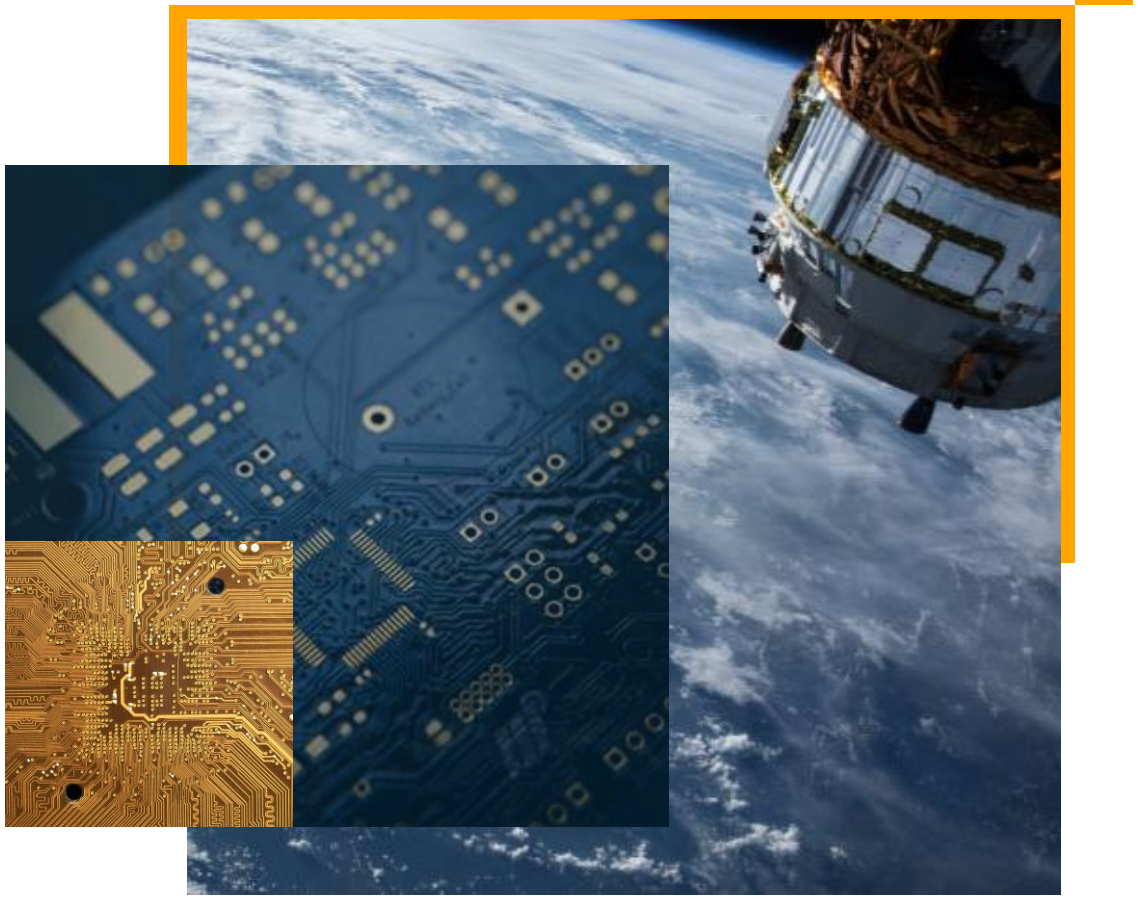
“Tough As Nails” Technology





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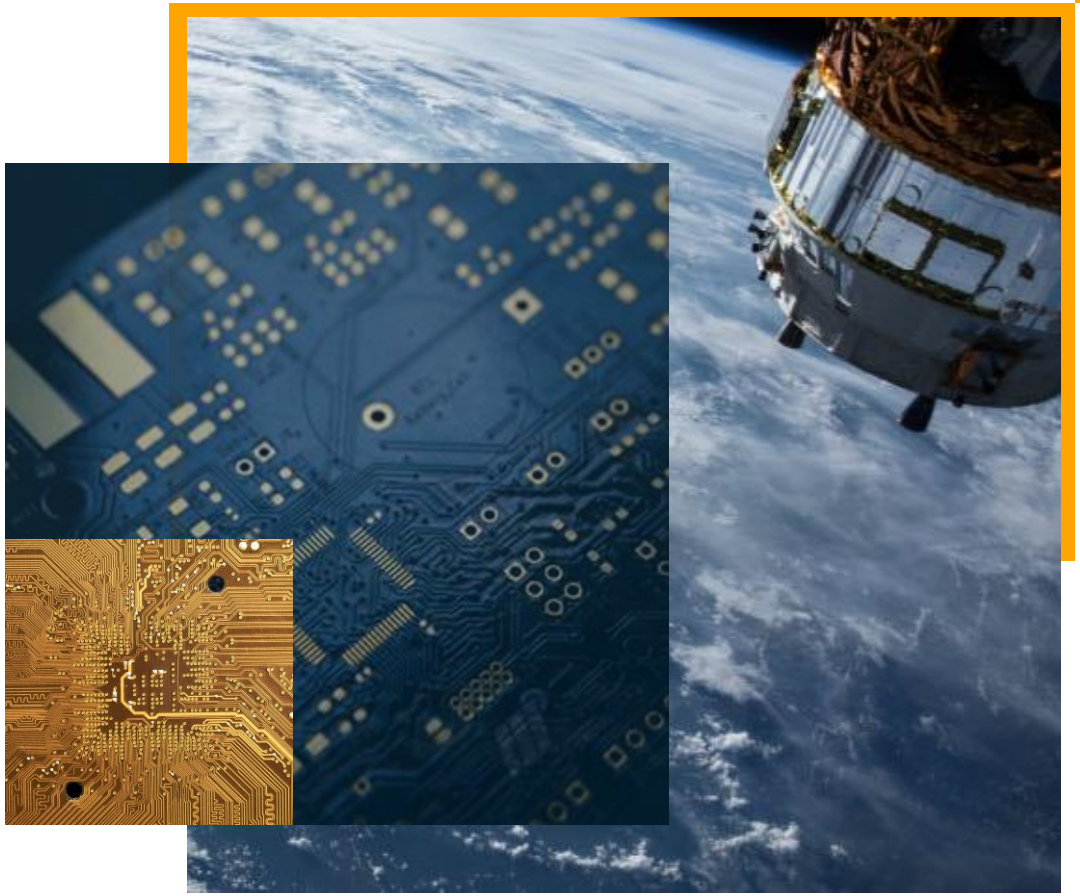
Q & A



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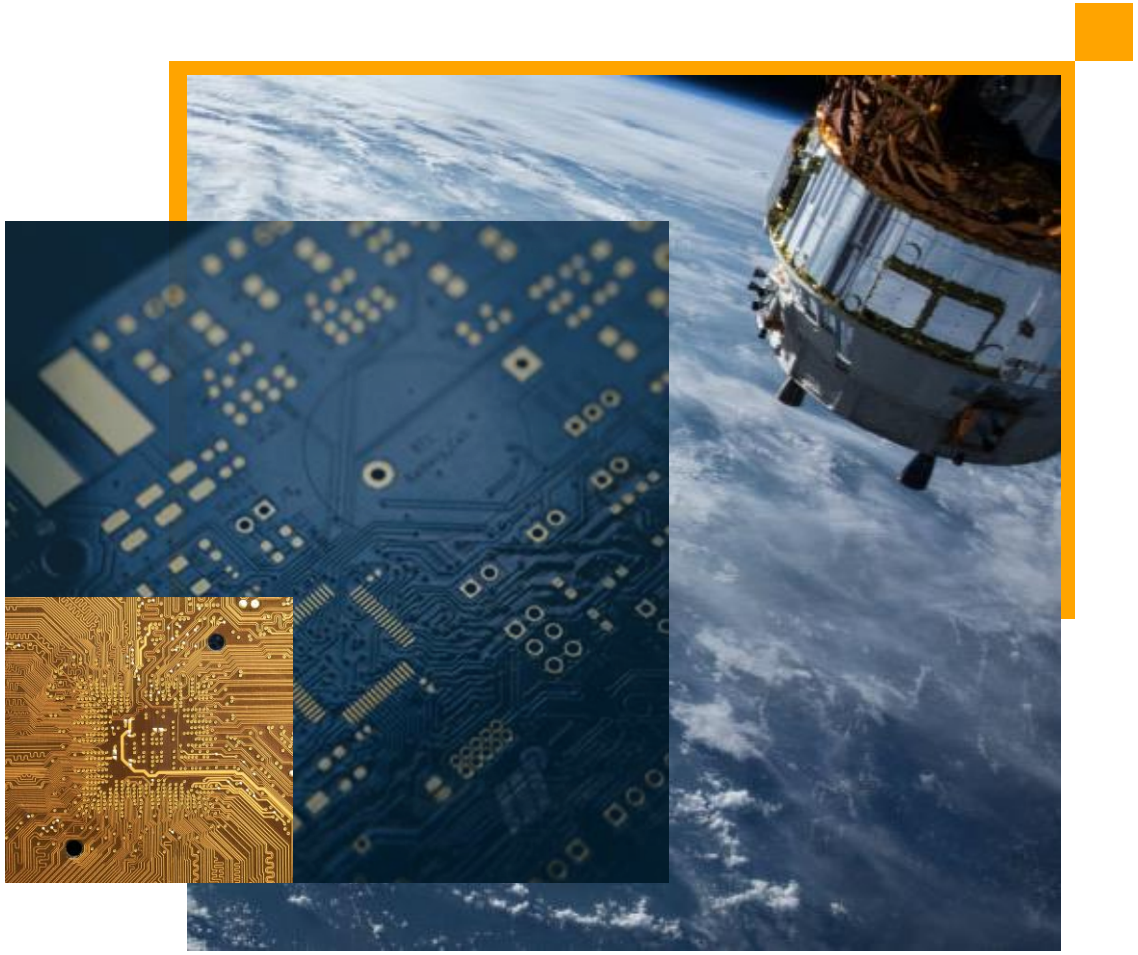

Thank You!

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