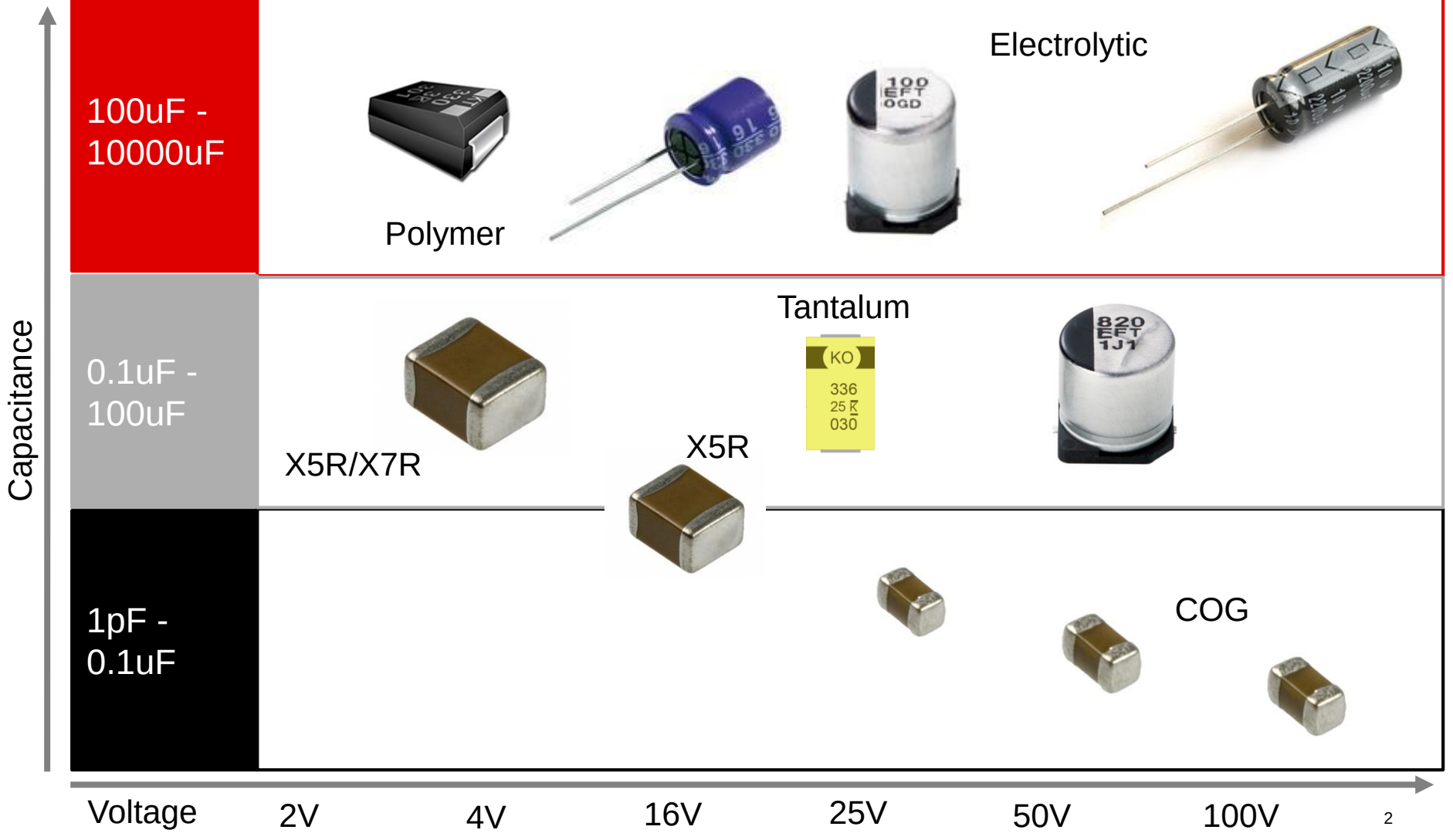
Switching Power Supply Component Selection

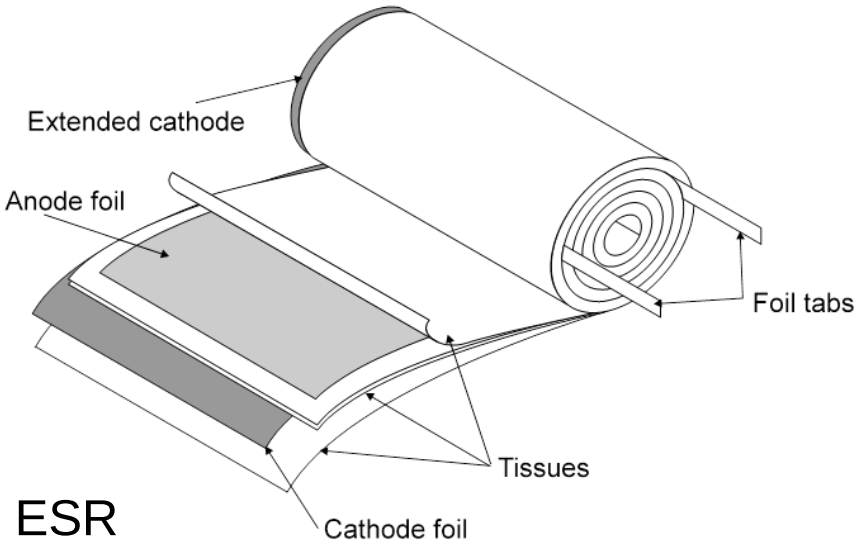
7.1b Capacitor Selection – Types of Capacitors

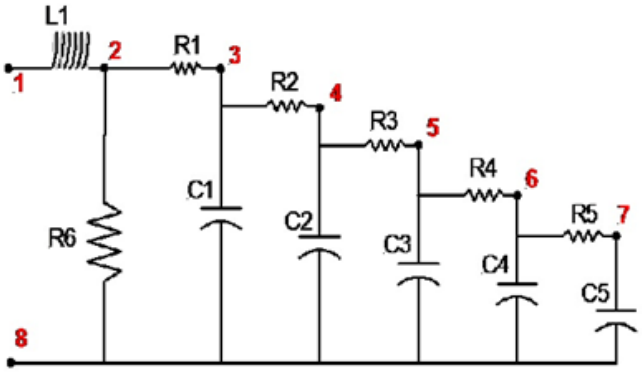
Capacitor Chemistry: Value and Voltage rating



Aluminum Electrolytics: Overview

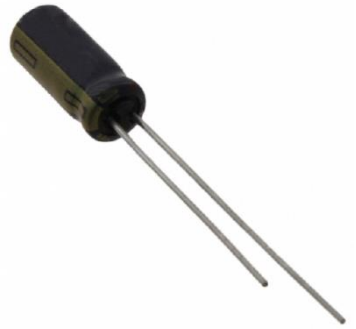
- **Least Expensive** Capacitors for Bulk Capacitance
  - Multiple vendors
  - Small size, surface mountable
- How is it made?
  - Etched foil with liquid Electrolyte
  - Placed in a can with a seal/vent
- **Highest ESR**
- Low Frequency Cap roll off due to higher ESR
- Wear Out Mechanism – **Limited lifetime**
  - Liquid electrolyte – with a vent
  - Cap changes over time with Voltage and Temp
  - ESR changes over time
- Mounting
  - High shock and vibration can cause failure





Aluminum Electrolytics: Packaging

- Through hole versions, usually in a round can
  - Large ones have screw terminals or solder lugs
  - Radial or axial leads
  - Non SMT may have higher inductance because of long leads
- Surface mountable versions, are modified from radial leaded versions
  - SMT versions usually have the capacitor value visibly printed on can
  - SMT versions may use letter codes instead of numeric rating



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Aluminum Electrolytics

Advantages | **Disadvantages**

- Low Cost
  - Mature technology with low cost materials
- Long History
  - (Industry started in the 1930's)
- Many Manufacturers to choose from.
- High capacitance values available.
- Only choice for SMPS that need high voltage and high capacitance.

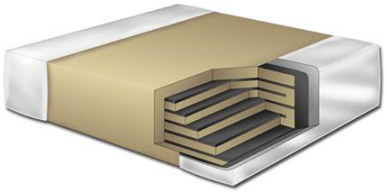
Aluminum Electrolytics

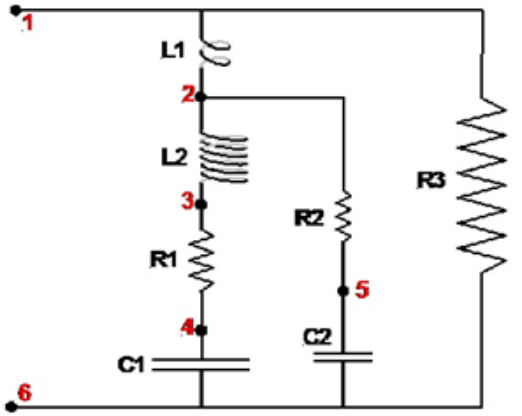
Disadvantages

- Large Parasitics
  - High ESR (Effective Series Resistance)
  - High ESL – (Effective Series Inductance).
- Electrolytic capacitors eventually degrade over the life of the product.
  - The electrolyte eventually dries out.
  - Long term storage may cause Aluminum oxide barrier layer to de-form.
    - Capacitance drops
    - ESR increases.
      - Higher ESR causes more internal heat causing it to dry out even faster.
      - This effect is worse at high temperatures.
  - (Lesson: Don’t use “old stock” aluminum capacitors in your product.)
- Needs a ceramic in parallel for switch mode applications.
  - High ESR and ESL can cause SMPS malfunction.
- Have measurable dc leakage current.
  - Probably not an issue in power circuits;
    - Leakage current can be a problem in timing circuits.

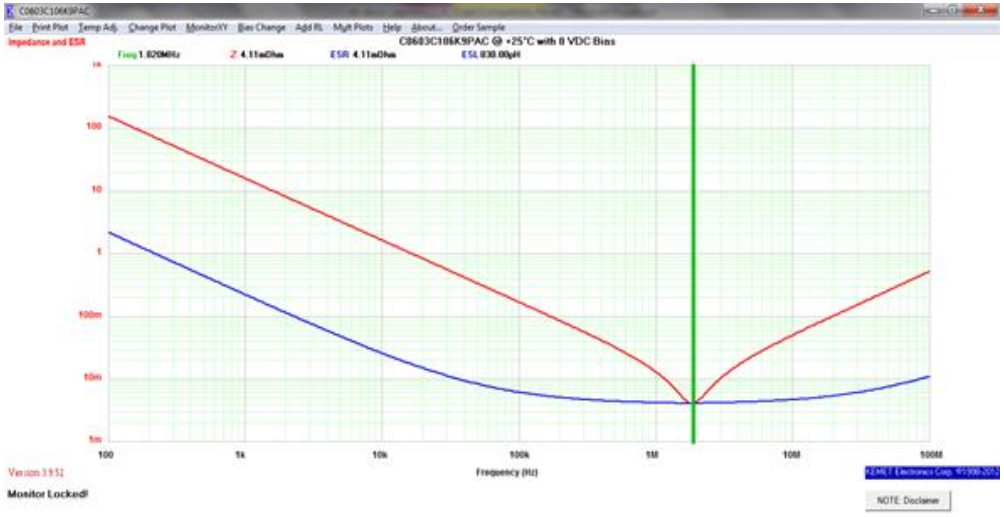
Ceramics: Overview

- Lowest Cost devices
  - Primarily for decoupling and bypass applications
  - Multiple vendors, sizes
  - Surface mountable
- How is it made?
  - Alternating layers of electrodes and ceramic dielectric materials





- Significant effects for Class 2 Dielectrics i.e. X5R, X7R
  - Voltage bias effect
  - Temperature effects
  - Ageing
    - 2%/decade hour for X7R
    - 5%/decade hour for X5R
    - Starts decay after soldering
  - High Q
    - Frequency selective



Ceramic Dielectric: 3 Character Codes

Class 1 (Best Performance)

- Temperature Coefficient Decoder

ppm/°C	
C	0.0
B	0.3
L	0.8
A	0.9
M	1.0
P	1.5
R	2.2
S	3.3
T	4.7
V	5.6
U	7.5

Multiplier	
0	-1
1	-10
2	-100
3	-1000
4	+1
6	+10
7	+100
8	+1000

Tolerance in ppm/°C (25-85 °C)	
G	±30
H	±60
J	±120
K	±250
L	±500
M	±1000
N	±2500

- Typical Values:
  - NP0,C0G, values up to 100,000pF

Class 2 (Higher Capacitance)

- Temperature and Capacitance Tolerance Decoder

Minimum temperature	
X	-55 °C
Y	-30 °C
Z	+10 °C

Maximum temperature	
4	+65 °C
5	+85 °C
6	+105 °C
7	+125 °C
8	+150 °C
9	+200 °C

Capacitance change permitted	
A	±1.0%
B	±1.5%
C	±2.2%
D	±3.3%
E	±4.7%
F	±7.5%
L	+15% / -40%
P	±10%
R	±15%
S	±22%
T	+22% / -33%
U	+22% / -56%
V	+22% / -82% [1]

- Typical Values:
  - X5R,X7R, values up to 150uF

Ceramic Capacitors

Advantages	Disadvantages

- Low Cost
  - Mature technology with low cost materials
- Many Manufacturers to choose from.
- Reliable and rugged
  - Extremely tolerant of over voltage surges
- Best Choice for local bypassing
- Not Polarized
- Lowest effective series resistance (Low ESR)
  - several milliohms
  - Leads to high RMS current rating
- Low effective series inductance (Low ESL)
  - < 3nH

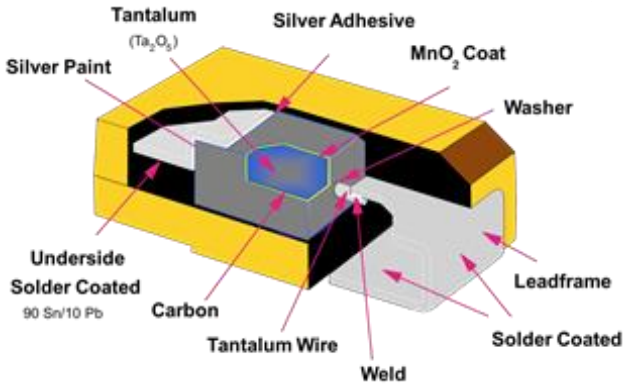
Ceramic Capacitors

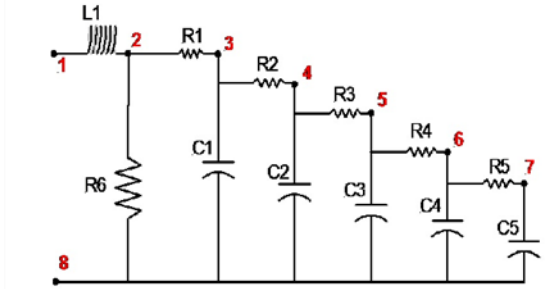
Disadvantages

- Capacitance limited to around 150 uF / 6.3V
- Large body sizes prone to cracking with PCB flexing. Several small units in parallel may be a better choice.
- Have both a voltage and temperature coefficient that reduces capacitance value.
- Some large package size units exhibit piezo-electric audible “singing”.
  - Difficult to control. (Ceramic speaker effect.)
  - More noticeable with Class 2 dielectrics
- Incomplete data sheets!!
  - ESR, ESL, SRF and Ripple Current rating often missing from data sheets
  - Contact the manufacturer for ripple current
- Capacitance value not printed on SMT device package.
  - Impossible to visually inspect for value once mounted on the PCB.
- Some power supply circuits are not stable with ceramic output capacitors.
  - Usually LDO’s and parts using COT control

Tantalum: Overview (MnO2 based)

- High Capacitance per unit Volume Technology
  - Small package sizes available
    - Thin devices are available
- How is it made?
  - Tantalum Anode pressed around a tantalum wire
  - Oxide grown on surface
  - Cathode formed by dipping and heat conversion Mn→MnO_2
  - Epoxy encapsulated
- Old technology
  - Requires 50% Voltage derating
    - PPM failure rates increase exponentially above 50% voltage derating
  - Can fail **explosively**
  - High ESR compared to Polymer types
  - Fairly low cap roll off vs. frequency

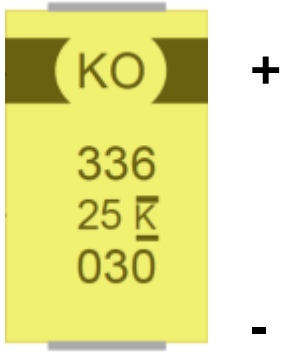


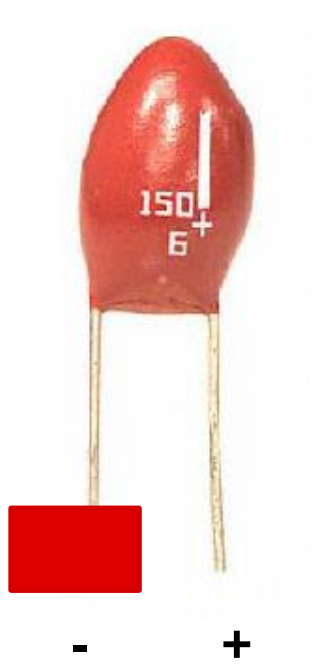


Tantalum Model

Solid Tantalum Capacitors: Packaging

- Usually rectangular Surface Mount Technology – SMT machine mountable
- Capacitance ratings for 1uF to 1000uF





Solid Tantalum Capacitors

Advantages

- Lots of capacitance in a small package.
  - 1uF to 1000uF max
- Medium-high effective series resistance (Low ESR)
  - 10 to 500 milliohms
  - Medium level of RMS current
- Low effective series inductance (Low ESL)
  - < 3nH
- Numerous manufacturers
- Good datasheet vs. electrolytic

Disadvantages

Solid Tantalum Capacitors

Advantages	Disadvantages

- Limited voltage range 50V rating max
  - Therefore for circuit voltages less than 25 or 35VDC
- Fairly high in cost
  - Historically Tantalum has had supply shortages
- Limited inrush surge current capability
  - Do not use tantalum for hot pluggable input capacitors!

Don’t Hot plug tantalum!

Solid Tantalum Capacitors Application Safety

- ALWAYS

  - Observe voltage polarity

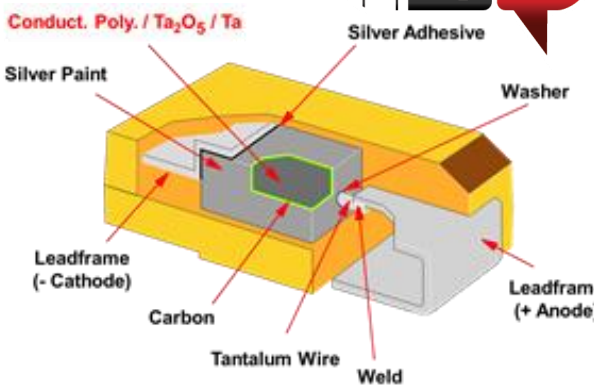
- DO NOT

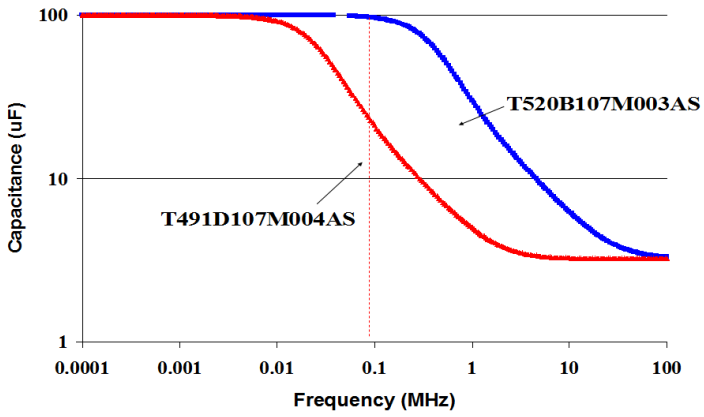
  - Exceed voltage rating
  - Exceed inrush surge rating

- Potential Outcomes
  - Can fail catastrophically if misapplied
  - Can fail open or short

Polymer - Overview

- Highest Capacitance per unit Volume Technology
  - Small package sizes available
- How is it made?
  - Tantalum Anode pressed around a tantalum wire
  - Oxide grown on surface
  - Cathode formed by dipping into Monomer and cured at room temperature
  - Epoxy encapsulated
- Lower ESR vs MnO2 based Tantalums
  - Higher frequency operation – over a Mhz…still looks like a cap!
  - Lower power dissipation
    - Higher ripple current capabi
    - May need less capacitance



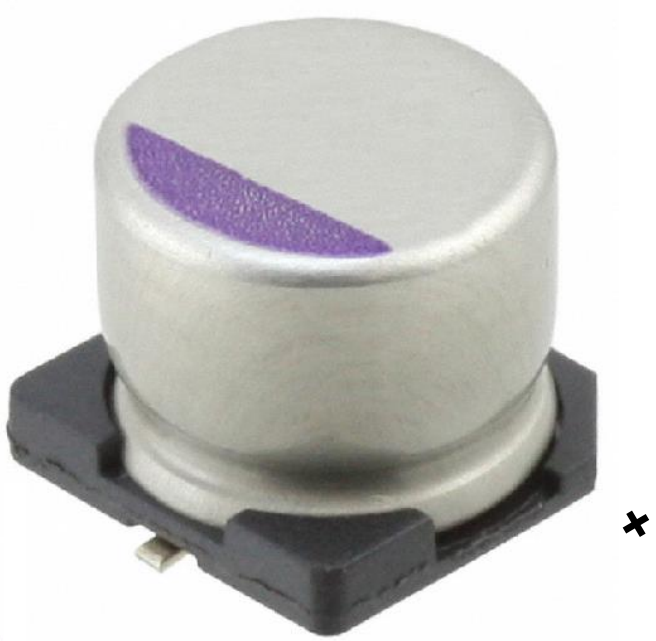


Polymer & Organic Capacitors: Packaging

- SMT Block style similar to tantalum.
- Round / Radial versions in SMT and through-hole.
- Types
  - Tantalum polymer / Aluminum polymer / Organic semiconductor

Kemet Tantalum Polymer

PosCap



OSCON

Polymer & Organic Capacitors

Advantages

- Low ESR
  - but not as low as equivalent ceramic.
- Low ESL
  - depending on construction method
- New technology
  - Designed for SMPS.
- Can be very low profile.
- High capacitance per unit volume.
  - Much better performance than aluminum electrolytic and much smaller in size.
- No voltage coefficient.
- Viable alternative to solid tantalum.

Disadvantages

Polymer & Organic Capacitors

Advantages	Disadvantages

- High cost
- Voltage surges capability depends on chemistry.
  - Oscon very intolerant of voltage surges
- Tend to be from a single supplier.
  - May have availability issues.

Polymer & Organic Capacitors Failure Mode

- Tantalum Polymer
  - Less prone to catastrophic failure than solid tantalum but will still vent and emit smoke.
- Organic (OSCON)
  - Emits noxious smoke.

QUICK COMPARISON CHARTS

Capacitor Chemistry: Quick Comparison

	Al-Elect	Ta	Ceram	Al-Poly	Film
ESR	5	4	1	3	2
ESL	5	3	1	3	3
DCL	5	3	1	4	2
Self-Healing	Yes (Reform)	Yes	No	Yes	Yes
Wear-Out	Yes	No	Aging	No	No
Shelf Decay	Yes	No	No	No	No
Volumetric Eff.	4	1	3	2	5
Over-Volt Capability	3	5	1	2	4
Cost	2	3	1	3	5
Pb-Free	No	Yes	Yes	Yes	Yes
Failure Mode	Open/Short	Short	Short	Short	Open/Short
Piezoelectric	No	No	Yes	No	No

Numerical Rankings from 1 (Best) to 5 (Worst)

Capacitor Chemistry: General Parameters

Characteristic	PET (MKT)	PEN (MKN)	PPS (MKI)	PP MKP/KP	COG (NPO)	X7R	X8R	Tantalum MnO2	Tantalum Polymer	Aluminum Polymer	Aluminum Electrolytic
Operating Temperature Range (°C)	-55° to 125°	-55° to 125°	-55° to 140°	-55° to 105°	-55° to 125°	-55° to 125°	-55° to 150°	-55° to 125°	-55° to 105° -55° to 125°	-55° to 105° -55° to 125°	-55° to 105°
Temperature characteristic (C/C)	±5%	±5%	±1.5 %	±1.5%	0 ± 30ppm	±15 %	±10 %	±10%	±10%	±10%	25 to -30%
DC Voltage Coefficient (%) at Vr	Negligible	Negligible	Negligible	Negligible	Negligible	-20%	±15 %	Negligible	Negligible	Negligible	10 to -15%
Aging Rate (%/hr/Decade)	Negligible	Negligible	Negligible	Negligible	Negligible	2%	1%	N.A.	N.A.	N.A.	N.A.
Dissipation Factor (%) 1 KHz		0.8	0.2	0.05	0.1	2.5	3.5	8	8	8	5
10 KHz	1.5	1.5	0.25	0.5	0.1						20
100 KHz	3.0	3.0	0.5	1							
ESR	low	low	very low	very low	low	Moderate to high	Moderate to high	high	Low to Moderate	Low to Moderate	high
Insulation Resistance (MΩxμF) 25°C	10,000	10,000	10,000	10,000	10,000	1,000	1,000	100	10	17	500
85°C	1,000	1,000	1,000	1,000	1,000	500	200	10	1	1.7	5
Dielectric absorption (DA) (%)	0.5	1	0.2	0.05	0.6	2.5	1	0.5	0.5	0.5	N.A.
Capacitance Range	1000pF to 10μF	1000pF to 6.8μF	100pF to 1μF	100pF to 10μF	0.5pF to 1μF	100pF to 4.7μF	100pF to 1μF	0.1μF to 1500μF	10μF to 1500μF	6.8μF to 470μF	0.1μF to 100μF
Capacitance Tolerances (±%)	5; 10	5; 10	2.5; 5	5; 10; 20	5; 10	10; 20	5; 10; 20	5;10; 20	20	20	-20 +50
Failure Mode Self Healing	Open Yes	Open Yes	Open Limited	Open Yes	Short No	Short No	Short No	Short Limited	Short Limited	Short Limited	Short Limited
Reliability	High	High	High	High	High	Moderate	Moderate	High	High	High	Low
Piezoelectric effect	No	No	No	No	No	Yes	Yes	No	No	No	
Resistance to thermal and mechanical shock	High	High	High	High	Low	Moderate to Low	Low	High	High	High	
Non-Linear distortion (3rd harmonic)	Very Low	Very Low	Very Low	Very Low	Low	High	High	N.A.	N.A.	N.A	High
Polar	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
260°C Pb-Free Capable	Not Yet	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No

Thank you!