Not All Caps Are Created Equal……
November 4, 2015
IEEE – Long Island Chapter – EMC Society
AGENDA

• Overview
• Capacitor Grades
• Capacitor Fundamentals
• Ceramics
  • Construction
  • Characteristics
• Tantalum & Polymers
  • Construction
  • Characteristics
• Decoupling
• Film
  • Construction
  • Characteristics
  • Products
• Tokin Products
  • EMI Cores
  • Flex suppressors
• K-Sim (formally Kemet SPICE)
KEMET Offers 98% of Dielectric Solutions

Voltage Range:
- 1V to 10KV

Capacitance Range:
- 1 pF to 1 F

Types of Capacitors:
- Aluminum Electrolytic
- Ceramic Film
- Tantalum
- EDLC (Electrical Double Layer Capacitor)
Product Development Drivers

“More Capacitance in a Smaller Package for less Cost”

- Size Constraints & Miniaturization
  ✓ Mechanical and Electrical
- Robust, high reliability
  ✓ Mechanical and Electrical
- Lower Parasitics
  ✓ ESR
  ✓ ESL
- Higher
  ✓ Energy Density
  ✓ Power Density
  ✓ Frequency
  ✓ Voltage
  ✓ Temperature
  ✓ Vibration
- Application Specific Requirements
  ✓ Custom Solutions
- Cost reductions
  ✓ Material set optimization
  ✓ Manufacturing efficiencies

Capacitance = \( \varepsilon \frac{A}{d} \)

\( \varepsilon \) = Dielectric Constant
A = Active area on plates
d = dielectric thickness
## Dielectric Comparison Chart

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>PET  (MKT)</th>
<th>PEN  (MKN)</th>
<th>PPS  (MKI)</th>
<th>PP  MKP/KP</th>
<th>COG  (NPO)</th>
<th>X7R</th>
<th>X8R</th>
<th>Tantalum MnO2</th>
<th>Tantalum Polymer</th>
<th>Aluminum Polymer</th>
<th>Aluminum Electrolytic</th>
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</thead>
<tbody>
<tr>
<td>Operating Temperature Range (°C)</td>
<td>-55° to 125°</td>
<td>-55° to 125°</td>
<td>-55° to 140°</td>
<td>-55° to 125°</td>
<td>-55° to 125°</td>
<td>-55° to 125°</td>
<td>-55° to 150°</td>
<td>-55° to 125°</td>
<td>-55° to 125°</td>
<td>-55° to 105°</td>
<td>-55° to 105°</td>
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<tr>
<td>Temperature characteristic (°C)</td>
<td>± 5%</td>
<td>± 5%</td>
<td>± 1.5%</td>
<td>± 1.5%</td>
<td>0 ± 30ppm</td>
<td>± 15%</td>
<td>± 10%</td>
<td>± 10%</td>
<td>± 10%</td>
<td>± 10%</td>
<td>± 10%</td>
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<tr>
<td>DC Voltage Coefficient (%) at Vr</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
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<td>Aging Rate (%hr/Decade)</td>
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<td>Negligible</td>
<td>Negligible</td>
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<td>Dissipation Factor (%)</td>
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<td>ESR</td>
<td>low</td>
<td>low</td>
<td>very low</td>
<td>very low</td>
<td>low</td>
<td>Moderate to high</td>
<td>Moderate to high</td>
<td>high</td>
<td>Low to Moderate</td>
<td>Low to Moderate</td>
<td>high</td>
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<td>Insulation Resistance (MΩxµF) 25°C</td>
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<td>10,000</td>
<td>10,000</td>
<td>10,000</td>
<td>10,000</td>
<td>1,000</td>
<td>1,000</td>
<td>100</td>
<td>10</td>
<td>17</td>
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<td>500</td>
<td>200</td>
<td>10</td>
<td>1</td>
<td>1.7</td>
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<td>85°C</td>
<td>0.5</td>
<td>1</td>
<td>0.2</td>
<td>0.05</td>
<td>0.6</td>
<td>2.5</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
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<td>N.A.</td>
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<td>Dielectric absorption (DA) (%)</td>
<td>100pF to 6.8µF</td>
<td>100pF to 10µF</td>
<td>100pF to 10µF</td>
<td>0.5pF to 1µF</td>
<td>100pF to 4.7µF</td>
<td>100pF to 1µF</td>
<td>0.1µF to 1500µF</td>
<td>10µF to 1500µF</td>
<td>6.8µF to 470µF</td>
<td>0.1µF to 100µF</td>
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<tr>
<td>Capacitance Range</td>
<td>5; 10</td>
<td>5; 10</td>
<td>2.5; 5</td>
<td>5; 10; 20</td>
<td>5; 10</td>
<td>10; 20</td>
<td>5; 10; 20</td>
<td>5; 10</td>
<td>20</td>
<td>20</td>
<td>-20 +50</td>
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<td>Capacitance Tolerances (± %)</td>
<td>Open</td>
<td>Open</td>
<td>Open Limited</td>
<td>Open Short No</td>
<td>Short No</td>
<td>Short No</td>
<td>Short Limited</td>
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<td>Reliability</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
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<td>High</td>
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<td>Piezoelectric effect</td>
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<td>No</td>
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<td>Yes</td>
<td>No</td>
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<td>Resistance to thermal and mechanical</td>
<td>High</td>
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<td>High</td>
<td>High</td>
<td>Low</td>
<td>Moderate to Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
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<td>High</td>
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<td>Non-Linear distortion (3rd harmonic)</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Low</td>
<td>High</td>
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<td>Polar</td>
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<td>No</td>
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<td>No</td>
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<td>260°C Pb-Free Capable</td>
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<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</table>
Differences in Capacitor Grades

Low Voltage DC Applications
Commercial

Low Cost
- Most Aggressive Design
- Changes On-Going
- Broadest Product Selection
Automotive: Robust
- Conservative (Commercial) Design
- Qualified, Produced, Screened: AEC-Q200
- Locked Design w/ Change Notifications
- Subset of Commercial
COTS (Commercial “Off-The-Shelf”)

Ceramic COTS
- Conservative Commercial / Automotive with Military Screening
- Mil Spec Testing, Design Extension
- BME vs PME

Tantalum COTS
- Conservative Commercial / Automotive with Military Screening
- Mil Spec Testing, Design Extension
- Mil Spec Extension of Design, Construction & Test
MIL-PRF

- MIL-PRF
- “Mil Spec”
- e.g. MIL-PRF-55681
Space Grade

- SPACE
- Conservative MIL-PRF
  - e.g. MIL-PRF-123
- DLA Qualified or Extension
Custom

• Based on Source Control Drawings
Capacitor Grade Examples

Surface Mount Multilayer Ceramic Chip Capacitors (SMD MLCCs)
Commercial Off-the-Shelf (COTS) for Higher Reliability Applications, X7R Dielectric, 6.3VDC-200VDC

Overview
KEMET’s COTS program is an extension of our capability and knowledge regarding high-reliability test criteria and requirements. As an established and trusted supplier of “up-screened” products, the COTS program was developed in response to the growing demand within the defense, aerospace, automotive, medical, and consumer electronics industries for lower cost and commercially available products that offers the same high quality and high reliability as up-screened products. The COTS program addresses this demand and integrates commercial grade products with high-reliability testing and inspection protocols that provide the accelerated conditioning and 100% screening necessary to eliminate infant mortality failures from the population.

KEMET’s X7R dielectric features a 125°C maximum operating temperature and is considered “stable.” The Electronic Components, Assemblies & Materials Association (EIA) characterizes X7R dielectric as a Class I material. Components of this classification are temperature compensating and suited for resonant circuit applications or those where Q and stability of capacitance characteristics are required. X7R exhibits no change in capacitance with respect to time and voltage and boasts a negligible change in capacitance with reference to ambient temperature. Capacitance change is limited to ±30 ppm/°C from -55°C to +125°C.

Benefits
- -55°C to +125°C operating temperature range
- RoHS Compliant
- EIA 0201, 0402, 0603, 0805, 1206, 1210, 1808, 1212, 1620, 2220, and 2225 case sizes
- DC voltage ratings of 10 V, 16 V, 25 V, 50 V, 100 V, and 200 V
- Capacitance offerings ranging from 5.5 pF up to 0.47 μF
- Available capacitance tolerances of ±10 pF, ±10.25 pF, ±10.5 pF, ±1%, ±2%, ±5%, ±10%, and ±20%
- No pre-electric noise
- Extremely low ESR and ESL
- High thermal stability
- High ripple current capability
- Preferred capacitance solution at line frequencies and into the MHz range

Ordering Information

High Reliability KEMET Organic Capacitor (KO-CAP)
T540 Polymer Commercial Off-the-Shelf (COTS) Series

Overview
The T540 Series KO-CAP offers the same advantages as the T22S Series but is also designed for the Commercial Off-the-Shelf (COTS) requirements of defense and aerospace applications. This surface mount product offers a tin lead (SnPb) leadframe finish, surge current testing options and standard or low ESR levels.

Benefits
- Polymer cathode technology
- 125°C maximum operating temperature
- High frequency capacitance retention
- Resistive failure mode

Applications
Typical applications include decoupling and filtering in defense and aerospace applications that require low ESR or a benign failure mode.

MIL-PRF (CWR Style) Established Reliability
T409 Series CWR09 Style MIL-PRF-55365/4

Overview
The T409 Series is approved to MIL-PRF-55365/4 (CWR09) with Weibull failure rates of B level (0.1% failures per 1,000 hours), C level (0.01% failures per 1,000 hours), D level (0.001% failures per 1,000 hours), or T level (0.01% failures per 1,000 hours), Option C surge current, DPA, Radiographic inspection, 100% visual inspection, DCL and ESR measurements within ±3 standard deviations, and Group C inspection). This CWR09 product is a precision-molded device with compliant terminations and inscribed laser marking. Tape and reeling per EIA 481-1 is standard.

Benefits
- Established reliability options
- Taped and reeled per EIA 481-1
- Symmetrical, compliant terminations
- Laser-marked case
- 100% surge current test available on all case sizes
- Qualified to MIL-PRF-55365/4, Style CWR09
- Termination options B, C, H, K
- Weibull failure options B, C, D, and T
- Exponential failure rates M, P, R, S
- Voltage rating of 4 – 50 VDC
- Operating temperature range of -55°C to +125°C

Applications
Typical applications include decoupling and filtering in Military and aerospace applications requiring CWR09 devices.
Capacitor Fundamentals
Parasitics
All capacitors utilize the same basic mechanism in their structure.

The value of a capacitor is measured in farads. For 1 farad of capacitance, 1 coulomb of charge is stored on the plates, when 1 volt of force is applied.

$$1 \text{ farad} = 1 \text{ coulomb} / 1 \text{ volt}$$

1 coulomb represents $\sim 6 \times 10^{19}$ electrons
“Pure” Capacitor

\[ Z = X_C = \frac{1}{2\pi fC} \]

Where:

- \( f \) is frequency (Hertz)
- \( C \) is capacitance (Farads)
Capacitor with Equivalent Series Resistance

\[ |Z| = \sqrt{X_C^2 + ESR^2} \]

Impedance vs. Freq.
47 \( \mu \)F Capacitance

- 0.25 Ohms ESR
- 0.10 Ohms ESR
- 0.05 Ohms ESR
- 0.01 Ohms ESR
- 0.001 Ohms ESR

Frequency (kHz)
Capacitor with Equivalent Series Resistance and Inductance

\[ |Z| = \sqrt{\left| X_C \right|^2 - \left| X_L \right|^2 + |ESR|^2} \]

\[ X_L = 2\pi f L \]

Where: \( L \) is in Henries

\[ f = \frac{1}{2\pi\sqrt{LC}} \]

self-resonant frequency.

**Impedance vs. Freq.**

47 \( \mu \)F Capacitance with 2.5 nH ESL

- 0.25 Ohms ESR
- 0.10 Ohms ESR
- 0.05 Ohms ESR
- 0.01 Ohms ESR
- 0.001 Ohms ESR
Transient Response
(C+ESR+ESL)

Capacitance: 200 μF
ESR: 33 mΩ
ESL: 100 nH

Voltage recovery from Power Supply Unit (PSU)

ESR Voltage drop
Capacitance Induced Voltage drop
ESL Voltage Spikes

Load Current 500mA

20mv per division
Ceramic Capacitors
(MLCCs)

Design and Characteristics
Multilayer Ceramic Capacitor (MLCC)

Typical Construction

- Ceramic Dielectric
- Internal Electrode (Ni for BME, Ag/Pd for PME)
- Termination (External Electrode, Cu for BME, Ag for PME)
- Barrier Layer (Plated Ni)
- Plated Sn finish for Solderability
Ceramic Capacitance Structure

Termination

Electrodes

Ceramic

\[ C = \varepsilon_0 K A (n - 1) d \]

Capacities in parallel are additive:

\[ C_T = C_1 + C_2 + C_3 + \ldots + C_n \]

- Design Capacitance
- Dielectric Constant
- Overlap Area
- Ceramic Thickness
- Number of Electrodes
Dielectric Technology

Commercial & Automotive Grade Dielectric Materials

C0G
- PME & BME
- Under Development
- 200°C

U2J
- Under Development

X8R
- BME

X8L
- BME

X7R
- PME & BME
- 175°C

Military & Hi-Rel Dielectric Materials

BP
- PME
- BME
- C0G @ Rated V

BX
- PME
- BME
- X7R +15/25% @ Rated V

BR
- PME
- BME
- X7R & +15/-40% @ Rated V
Trend in BME MLCC Technology:
Dielectric Thickness and Layers Count Progression

0.1 µF/50V (PME)
(12 µm layers, n= 30 )

1.0 µF/25V (PME)
(8 µm layers, n=100 )

22 µF/6V
(500 1.8 µm layers)

2000- 4.7 µF/16V
(225 4 µm layers)

10 µF/6V
(300 3 µm layers)

47 µF/4V
(600 1 µm layers)

Class 2 1206 (EIA)

1988

Today
Characteristics
Relative Capacitance vs. Temperature

['K' Magnitude]

Temperature

Z5U

X5R

X7R

Y5V

U2J

C0G (NP0)

'Room' Ambient
# Dielectric Classification
## Class I (Per EIA – 198)

### Class I Dielectrics: (Example: C0G)

<table>
<thead>
<tr>
<th>Alpha Symbol</th>
<th>Significant Figure of Temp Coefficient ppm/ºC</th>
<th>Numerical Symbol</th>
<th>Multiplier to significant figure</th>
<th>Alpha Symbol</th>
<th>Tolerance of Temp Coefficient ± ppm/ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>G</td>
<td>30</td>
</tr>
<tr>
<td>B</td>
<td>0.3</td>
<td>1</td>
<td>-10</td>
<td>H</td>
<td>60</td>
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<td>L</td>
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<td>7.5</td>
<td>9</td>
<td>+10000</td>
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</table>

Temperature Range: -55ºC to +125ºC

C0G provides highest temperature stability
# Dielectric Classification

**Class II and III (per EIA-198)**

<table>
<thead>
<tr>
<th>Alpha Symbol</th>
<th>Low Temperature (°C)</th>
<th>Numerical Symbol</th>
<th>High Temperature (°C)</th>
<th>Max cap change over temp. range (%)</th>
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</thead>
<tbody>
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<td>Z</td>
<td>+10</td>
<td>2</td>
<td>+45</td>
<td>±1.0</td>
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<td>Y</td>
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<td>4</td>
<td>+65</td>
<td>±1.5</td>
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<td>X</td>
<td>-55</td>
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<td>±2.2</td>
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<td>6</td>
<td>+105</td>
<td>±3.3</td>
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<td>7</td>
<td>+125</td>
<td>±4.7</td>
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<td>±7.5</td>
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<td>±10</td>
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<td>10</td>
<td>+220</td>
<td>±15</td>
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<td>11</td>
<td>+220</td>
<td>±22</td>
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* Industry Classification (Non EIA-198)

**CLASS II**

<table>
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<th>Low Temperature (°C)</th>
<th>Numerical Symbol</th>
<th>High Temperature (°C)</th>
<th>Max cap change over temp. range (%)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>12</td>
<td>+220</td>
<td>±33</td>
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<tr>
<td>U</td>
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<td>±56</td>
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<tr>
<td>V</td>
<td>+22</td>
<td>14</td>
<td>+220</td>
<td>±82</td>
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</tbody>
</table>

**CLASS III**

* Industry Classification (Non EIA-198)
Voltage Coefficient (Class II and III)
1210 vs 0805, X7R, 10µF, 6.3V

Capacitance Change vs. DC Bias

Rated 6.3V
Voltage Coefficient (Class II and III)

DC Bias – Loss of Dipoles

- **0 vdc**: Dipole Active
- **X vdc**: Dipole Inactive
- **5X vdc**: Dipole Locked

Electric field locks dipoles
Locked dipoles do NOT contribute to capacitance
X7R Aging Rate
3% per Decade Hour (Limit)

https://ec.kemet.com/design-tools/aging-calculator-for-ceramics
Piezoelectric Noise
Class II and III Only

Piezoelectricity
Mechanical forces can create electrical signals.

Electrostriction
Electrical forces can create mechanical distortion.

Ceramic Chip
Barium Titanate crystal cartridges
Electrostrictive Behavior in Barium Titanate

- $\text{O}^{2-}$ Oxygen
- $\text{A (Ba}^{+2}\text{ Barium)}$
- $\text{B (Ti}^{+4}\text{ Titanium)}$
Class 2 BaTiO$_3$
Ferroelectric

Ferroelectric dipoles in *domains* align with the AC Field.

Domain wall heating &
Signal distortion

Class 1 CaZrO$_3$
Paraelectric

Paraelectric dipoles align with AC field

No domains, so
No Domain wall heating &
Reduced signal distortion
Typical Crack Signatures
MLCC Cross-Sections

The major sources MLCC of cracks are:

- Mechanical damage (impact)
  - Aggressive pick and place
  - Physical mishandling

- Thermal shock (parallel plate crack)
  - Extreme temperature cycling
  - Hand soldering
    - *Do not touch electrodes while hand soldering!*

- Flex or Bend stress
  - Occurs after mounted to board
  - Common for larger chips (>0805)

*Failure is not always immediate!*
*Failure mode is not always deterministic!*
Flex Cracks

https://ec.kemet.com/q-and-a/what-is-failure-mode-for-ceramic-capacitors
Polymer (Tantalum) Capacitors

Design and Characteristics
Common Myths
Myth 1: The World Is Running Out Of Tantalum

Expected shortages of metals within the next 50-100 years include Copper, Gold, Silver, Indium, Platinum, Zinc and Lead.
Myth 2: Tantalum Is Only For Capacitor Production

Tantalum has many Applications

- Capacitors
- Resistors
- Hard Disk Drives
- Acoustic Filters
- Camera Lenses
- Phone Display
- Ink Jet Printers
- X-Ray Film
- Aircraft Frames
- Turbine Blades
- Jet Engine Discs
- Joint Replacement
- Skull Plates
- Screws/clamps
- Wires
- Rocket Nozzles
- Furnaces
- Cutting Tools
- Chemical Resistant

Niobium and Tantalum—Indispensable Twins

How Do We Use Niobium and Tantalum?

Tantalum has a unique ability to store and release energy, which is why the electronics industry consumes more than one-half of tantalum production. Tantalum-based components can be exceptionally small, and other elements cannot serve as substitutes without degrading the performance of electronic devices. As a result, tantalum is used in components for items as ubiquitous as cell phones, hearing aids, and hard drives. Tantalum’s low mechanical strength and high biocompatibility allow it to coat stronger substrates, like stainless steel, for medical applications. It is used for blood vessel support stents, plates, bone replacements, and suture clips and wire. In the chemical industry, tantalum’s corrosion resistance makes it useful as a lining for pipes, tanks, and vessels. Tantalum oxide can increase the refractive index of lens glass, while the hardness of tantalum carbide makes it an ideal component in the manufacture of cutting tools.

Only half of the world’s annual Tantalum output is used in capacitor production
Myth 3: World Demand For Tantalum Frequently Exceeds Available Supply

- Single source for ore
- Expensive hard rock operation
- When market price dropped below operating cost, the mine discontinued operations until metal prices increased.

- Multiple sources for ore
- Mix of artisanal (open pit) and hard rock operations.
- Multiple regions of the world.
- Mix of regions and mines result in a competitive market place.

Most of the shortages experienced in the industry were artificially created. In recent years, capacitor manufacturers have established broader supply chain networks to prevent this from occurring.
Myth 4: Tantalum Capacitors Do Not Possess a Safe Failure Mode

Tantalum Capacitor Classes:
- Wet Cathodes
- Solid Polymer Cathodes
- Solid MnO₂ Cathodes

The cause of the undesirable failure mode is the MnO₂ cathode. But users often define it as “Tantalum”.
Myth 5: Tantalum Capacitors Are Only Used In High End Applications

While Ta caps are not as frequently used as ceramic or aluminum, they are widely used in our daily lives.

It is likely that you carry 10 to 50 Tantalum capacitors with you everyday in your laptops, tablets, and smart phones.
Design
Why Use Tantalum?

- Stable C (No Temp or Bias Effects), DCL (t)
- Reliable (Decreasing FR)
- Long Life (Exceeds Expected Life of All Hardware)
- Most Volumetrically Efficient (CV/cc, E/cc)

**SEM of a Sintered Ta Anode**
Dielectric: Tantalum Pentoxide Ta$_2$O$_5$

- **Critical Characteristics**
  - Dielectric constant
    - 27.7
  - Dielectric breakdown
    - VBDV 470 volt/mm
  - Dielectric thickness:
    - 2.0 nm/volt
  - Resistant to chemical attack

<table>
<thead>
<tr>
<th>$V_R$</th>
<th>Ta</th>
<th>MLCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>20.7</td>
<td>600</td>
</tr>
<tr>
<td>4</td>
<td>27.6</td>
<td>600</td>
</tr>
<tr>
<td>6</td>
<td>36.8</td>
<td>600</td>
</tr>
</tbody>
</table>

Fractured Sintered Anodes With Dielectric Already Formed
Polymer Construction

**General**
- Dielectric
- Electrode
  - [Counter] Electrode

**Tantalum**
- Ta$_2$O$_5$ Dielectric
- Ta Metal
- Polymer

**KO-CAP Construction**
- Molded Epoxy Case
  - Polarity Stripe (+)
  - Polarity Bevel (+)
- Leadframe (- Cadode)
- Weld (to attach wire)
- Silver Adhesive
- Molded Epoxy Case

**Detailed Cross Section**
- Silver Paint (Fourth Layer)
- Tantalum Wire
- Carbon (Third Layer)
- Leadframe (+ Anode)
- Polymer (Second Layer)
- Ta$_2$O$_5$, Dielectric (First Layer)
- Tantalum

Ta Caps have a 3-D structure
- Interconnected Tantalum Particles
- Carbon Ink
- Silver Paint
- Ta$_2$O$_5$, Dielectric Layer

Counter Electrode Penetration into Pores (Polymer)
Polymer Cathode

Cathode forms the negative connection:

- Polymer is an intrinsically conductive polymer
- \( \text{MnO}_2 \) is manganese dioxide
Characteristics
RC-Ladder Effect

RC-Ladder effects are factored by both capacitance and resistance.

tc1 = C1 x R1

tc2 = C2 x (R1+R2)

tc3 = C3 x (R1+R2+R3)

tcn = Cn x (R1+R2+R3...+Rn)
Capacitance vs Frequency

Polymers are commonly used in applications of up to 1MHz. Applications exceeding 1MHz typical call for MLCC’s.
## Voltage Derating Guidelines

<table>
<thead>
<tr>
<th></th>
<th>Ta-MnO₂</th>
<th>Poly KO V₉&gt;10VDC</th>
<th>Poly KO V₉≤10VDC</th>
<th>Alum-Poly AO</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 PPM FR % V₉Rated</td>
<td>68%</td>
<td>126%</td>
<td>197%</td>
<td>235%</td>
</tr>
<tr>
<td>@50% V₉Rated FR(PPM)</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>@80% V₉Rated FR(PPM)</td>
<td>458</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>@90% V₉Rated FR(PPM)</td>
<td>1700</td>
<td>12</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>@100% V₉Rated FR(PPM)</td>
<td>6310</td>
<td>35</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Leakage Limit</td>
<td>0.01CV</td>
<td>0.1CV</td>
<td>0.1CV</td>
<td>0.04-0.06CV</td>
</tr>
</tbody>
</table>

- **Typical derating guidelines:**
  - Tantalum MnO₂: 50%
  - Polymer KO: 20%(>10V), 10% (≤10V)
  - Aluminum Polymer: 0%

- **Temperature Ratings:**
  - Tantalum MnO₂: 125ºC up to 230ºC
  - Polymer KO: 105ºC - 125ºC
  - Aluminum Polymer Gen I: 125ºC
  - AO Gen II: 105ºC - 125ºC (future)
  - MLCC (X5R): 85ºC
ESR and Impedance vs. Frequency
AO Gen II vs. TA Polymer

Impedance and ESR vs. Frequency
A720V227M006ATE vs T520V227M006ATE012
Capacitance vs. Frequency
AO Gen II vs. TA Polymer
3528 Footprint Impedance Frequency Data
AO Gen II B Case/KO Facedown B Case/1210 MLCC

Impedance and ESR vs. Frequency
5 Parts Tested Each Group - 25°C
Capacitance vs. Frequency
5 Parts Tested Each Group - 25C

- **AO Gen II B Case 150μF/2V Cap**
- **KO Facedown 270μF/2.5V Cap**
- **1210 MLCC 220μF/6.3V Cap**
Bias Voltage Capacitance

- One advantage of both polymer systems includes the stability of capacitance over varied bias from zero to rated voltage.
Applications Most Suitable For Polymer Capacitors
DC/DC Converter
Filtering, Decoupling, and Hold Up

Most polymer caps are used in DC/DC power converter applications

Voltage vs. Capacitance (μF) graph showing the capacitance range for different voltages with a focus on polymer tantalum capacitors.
Strengths And Weaknesses
By Dielectric
Polymer vs. High Cap MLCC

Delivered Capacitance

No Piezo Noise

Stable Capacitance

MLCCs have a narrow “sweet spot” for low impedance while polymer has a wide frequency range for BB apps.

One Polymer

Three MLCCs

Wider Low Impedance Range

1pc: 1210, 270uF, 2V, 6mOhm

<10m Impedance Range

Polymer

Parasitic

MLCC

Polymer Provides Stable Capacitance
(No Bias, Temperature, AC Ripple or Aging Effect)

1210, X5R, 100µF, 6V

1206, X5R, 100µF, 6V

1pc: 1210, X5R, 100µF, 6V
1pc: 1210, X5R, 47µF, 6V
1pcs: 0805, X5R, 2.2µF, 6V

<10m Impedance Range

1206, Polymer, 100µF, 6V, 15mOhm

Advertised (1V @ 25°C)
Biased Effect (5V)
Temperature Effect (65°C)
Frequency (300 kHz)
Aging Effect (10 Yrs)

Capacitance (µF)
Polymer vs. Aluminum Electrolytic

**Low Profile**

**Low ESR**

**Low ESL**

**Long Life**

**Stable Capacitance**

*Polymer Provides Stable Capacitance (No Dry out, Temperature Effect)*

**High Ripple Handling**

- Ripple Current (Amps)
  - Alum Lytic
  - Poly Ta

![Diagram](image_url)
Polymer vs. Traditional Tantalum

Non-Ignition Failure Mode

 Voltage Derating

Low ESR

Higher Capacitance
When Polymer Is Not The Ideal Choice

- **Frequencies Approaching 1MHz**
  - Cap vs Frequency results in too great of cap loss compared to MLCC.

- **Very Low Leakage Applications**
  - Polymer is higher in leakage than MnO$_2$ type technologies for applications seeking maximum battery life like hearing aids.

- **High Temperatures**
  - Applications exceeding 125°C are not ideal for polymer caps unless the expected life time use is short (days to weeks).

- **Low Capacitance**
  - Capacitance needs of picofarads or a few microfarads are too low to be offered in a polymer capacitor.
<table>
<thead>
<tr>
<th>Capacitor Type</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low ESR (T520)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5x2.8x2.0</td>
<td>9mΩ 2.5V330uF</td>
<td>6mΩ 2.5V330uF</td>
<td>4.5mΩ 2.5V330uF</td>
</tr>
<tr>
<td>3.5x2.8x1.2</td>
<td>18mΩ 6.3V150uF</td>
<td>15mΩ 6.3V220uF</td>
<td></td>
</tr>
<tr>
<td><strong>Low ESL/ESR (T528)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5x2.8x2.0</td>
<td>6mΩ 2.5V270uF</td>
<td>6mΩ 2.5V330uF</td>
<td>4.5mΩ 2.5V470uF</td>
</tr>
<tr>
<td>3.5x2.8x1.2</td>
<td></td>
<td>9mΩ 2.5V220uF</td>
<td></td>
</tr>
<tr>
<td><strong>High Cap (T520)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5x2.8x2.0</td>
<td>6.3V330uF</td>
<td>25mΩ 6.3V330uF</td>
<td></td>
</tr>
<tr>
<td>3.5x2.8x1.2</td>
<td></td>
<td>15mΩ 6.3V220uF</td>
<td></td>
</tr>
<tr>
<td><strong>Low Profile (T520/T521)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.3x4.3x1.5</td>
<td>6.3V680uF</td>
<td>16V330uF</td>
<td></td>
</tr>
<tr>
<td>3.5x2.8x1.2</td>
<td>16V33uF, 25V10uF, 35V6.8uF</td>
<td>25V15uF</td>
<td>35V15uF</td>
</tr>
<tr>
<td>3.5x2.8x1.0</td>
<td></td>
<td>6.3V150uF</td>
<td>16V33uF</td>
</tr>
<tr>
<td><strong>12V-48V Higher (T521)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.3x4.3x4.3</td>
<td>75V 6.8uF</td>
<td>35V100uF</td>
<td></td>
</tr>
<tr>
<td>7.3x4.3x2.0</td>
<td></td>
<td></td>
<td>35V47uF, 16V150uF</td>
</tr>
<tr>
<td><strong>High Temp/ High Humidity (T591/T598)</strong></td>
<td>3.5x2.8x1.2</td>
<td>500 Hrs 85/85 &amp; 125C (2-50V)</td>
<td>2.5V470uF 6mΩ (7.3x4.3x2.0)</td>
</tr>
<tr>
<td>7.3x4.3x2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.3x4.3x3.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5x2.8x1.2</td>
<td>1K Hrs 85/85 &amp; 125C (Full AEC Q-200) 2-16V</td>
<td>1K Hrs 85/85 &amp; 125C (Full AEC Q-200) 20-50V</td>
<td></td>
</tr>
</tbody>
</table>
Low ESL B Cases

Features:
- Small Footprint
- Low Profile
- High Capacitance
- Low ESR

<table>
<thead>
<tr>
<th>Case Size (LxWxH)</th>
<th>Cap (uF)</th>
<th>Voltage</th>
<th>ESR (mOhms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3528-20</td>
<td>270</td>
<td>2.5</td>
<td>6</td>
</tr>
<tr>
<td>3528-20</td>
<td>270</td>
<td>2.5</td>
<td>9</td>
</tr>
<tr>
<td>3528-12</td>
<td>220</td>
<td>2.5</td>
<td>9</td>
</tr>
</tbody>
</table>

Impedance & ESR vs Frequency

<6mOhms: 100KHz – 1MHz
### AEC Q-200 Rev D Table of Methods for Tantalum Capacitors

<table>
<thead>
<tr>
<th>Stress Test Name</th>
<th>Conditions</th>
<th>Std Poly Series</th>
<th>T591</th>
<th>T598</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Temp Exposure (Storage)</td>
<td>125° C, Unbiased, 1000 Hrs</td>
<td>X</td>
<td>✓*</td>
<td>✓</td>
</tr>
<tr>
<td>Temperature Cycling</td>
<td>-55° C to 125° C, 1000 Cycles</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Biased Humidity</td>
<td>85° C, 85% RH, Biased, 1000 Hrs</td>
<td>X</td>
<td>(500Hr)</td>
<td>✓</td>
</tr>
<tr>
<td>Operational Life</td>
<td>125° C, Biased, 1000 Hrs</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Resistance to Solvents</td>
<td>Mil-Std-202, Meth. 215</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Mechanical Shock</td>
<td>Mil-Std-202, Meth. 213, Cond F</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Vibration</td>
<td>Mil-Std-202, Meth. 208, 5G’s-20min</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Resistance to Soldering Heat</td>
<td>Mil-Std-202, Meth. 210, Cond D</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>ESD</td>
<td>AEC-Q200-002 or ISO/DIS 10605</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Solderability</td>
<td>J-STD-002</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Terminal Strength</td>
<td>AEC Q200-006</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

*105°C & 125°C Offerings. See Part Number Table.
Decoupling
Decoupling Principles

Introduction

IC

“I need some charge!”

Charge coming up!

“Bypass” Capacitor

• Eliminate High-Frequency Noise
• Decouple RC Delays
• Prevent Voltage Droop

Power Supply
Decoupling Principles
Different Caps for Different Needs

“High” ESR Electrolytics
- Filters low frequency noise
- Act as charge reservoirs to transient currents

Low ESR Electrolytics

Low ESL Ceramics
- Low inductance (ESL) and low ESR parts provide high frequency filtering
Decoupling Principles
Combining Impedance

Cascaded capacitors in parallel:
- Higher Impedance Bandwidth
- Reduction of ESR
- Lower Physical Inductance

Resultant ESR
1206-100nF
0805-10nF
0402 - 1nF
Decoupling Principles
Same Value Caps in Parallel

$$Freq = \frac{1}{2 \sqrt{nC} \cdot ESL}$$
Power Distribution Networks
Power Distribution Network (PDN)

Select Decoupling CAPS to Meet $Z_{TARGET}$

Larry Mosley’s (Intel) PDN Model

Response Time:
- 100’s ps
- 1’s ns
- 10’s ns
- 100’s ns
- 1’s µs

Frequency:
- 1 GHz
- 100 MHz
- 10 MHz
- 1 MHz
- 100 kHz

Power Distribution Network (PDN)

Impedance = PDN + Capacitor Network

\[ Z_{\text{Target}} = \frac{V_{\text{Rail}} \cdot \%\text{Ripple}}{100} \div I_{\text{Max}_\text{Transient}} \]
Filtering
Filtering Principles

Blocking of unwanted signals

Passing of wanted signals
Filtering Principles

Example: DC to DC Converter

<table>
<thead>
<tr>
<th>Capacitor Type</th>
<th>Frequency</th>
<th>$V_{in} &gt; 40V$</th>
<th>$V_{in} &lt; 40V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic</td>
<td>Mid to High</td>
<td>Good</td>
<td>Good, Low-Cost</td>
</tr>
<tr>
<td>Film</td>
<td>Mid to High</td>
<td>Good</td>
<td>Not Ideal</td>
</tr>
<tr>
<td>Aluminum Electrolytic</td>
<td>Low</td>
<td>Good, Low-Cost</td>
<td>Not Ideal</td>
</tr>
<tr>
<td>Polymer</td>
<td>Mid</td>
<td>Acceptable</td>
<td>Good</td>
</tr>
</tbody>
</table>
Example Input Filter

2.78V\text{ (PP)} without filtering

0.47V\text{ (PP)} with filtering
Example Power Distribution System

Input Caps Near Each Converter

Simplified Power Distribution Network
The DC to DC output voltage for a load transient can be defined as:

\[ V_{\text{out}}(t) = V_{\text{out\_initial}} - \text{ESL} \left( \frac{di_{\text{load}}}{dt} \right) \div ESR \cdot i_{\text{load}}(t) \]

The magnitude of the voltage drop is proportional to \( ESR \cdot i_{\text{load}} \) and can be compensated for when calculating initial values.

\[ C = I \cdot \frac{dt}{(dv \cdot (ESR \cdot i_{\text{load}}))} \]
Example Input Filter

- Cin1 is 100μF, 50V aluminum electrolytic (polar)
- Cin2, Cin3, Cin4, are X7R, 4.7μF, 50V, 10%, 1210

Linear Technology, DEMO MANUAL DC1477A
Simplified Power Distribution System

Input Power Connector from Power Supply

12 Vdc Input

Dc to Dc Converter

Return

0.9 - 1.1 Vdc Output

Return

1.2 - 1.5 Vdc Output

Return

2.0 Vdc Output

Return

2.5 Vdc Output

Return

3.3 Vdc Output

Return

Output Capacitor Families

- T520, T525 (2.5V), Low ESR, Polymers
- T528 (2.5V), Low ESR/ESL, Polymers
- A700 (2V), Low ESR, Polymers
- X7R and X5R (4V and 6.3V) Ceramics
- T49x, T409/19/29, T510 (2.5V or higher) Tantalums
- EDx, EEx, ESx EXx (4V or higher) Aluminum Electrolytics

Input Capacitor Families

For 12 volt input systems:

- T521, T520, T525 (16V or higher) Polymers
- A700 (12.5V or 16V) Polymers
- X7R or X5R (16V to 50V) Ceramics
- T49x, T409/19/29, T510 (25V or higher) Tantalums
- MDC, MDS, JSN (PET) (50V) Films
- EDx, EEx, ESx EXx (16V or higher) Aluminum Electrolytics

Notes:

- Cell Phone uses X5R Ceramics for input and output capacitors
- Automotive uses X7R (25 and 50V) Ceramics due to Load Dump on 12V input
- Military and Commercial aircraft – use 28 Volt input, T521/540/541 (35 and 50 volts) Polymers and X7R (50-100 volts) Ceramics for inputs
- Telecom uses 100V Films and Ceramics on 48V lines.
Decoupling Networks
Advantages of Capacitors in Parallel

- Increased bulk Capacitance
- Lower ESR
- Lower physical inductance
  - Larger caps have larger ESL
  - Smaller caps in parallel do not affect ESL
- Higher impedance bandwidth

\[ Freq = \frac{1}{2 \sqrt{\frac{ESL}{n^2} nC}} \]

Equal capacitors in *Parallel* do not alter the SRF
Calculating Target Impedance

- Needed for $Z_{\text{target}}$
  - Max transient Current
  - Rail Voltage
  - Max AC Ripple (% of Supply)
  - $f_{\text{Target}}$ is max switching frequency

$$Z_{\text{Target}} = \frac{V_{\text{Rail}} \cdot \%\text{Ripple}}{100 \div I_{\text{Max\_Transient}}}$$

Determine $Z(f)$ of PDN
Transform $Z$ spectrum into Time Domain
Integrate Transform
Subtract step response from VRM

http://www.electrical-integrity.com/

Simplified Wound Capacitor Production Process

Steps in Capacitor Production

- Plastic Raw Roll
- Metallizing
- Slitting
- Band
- Winding
- Flattening
- Protective Taping
- End Spraying
- Encapsulating & Resin Filling
- Measuring:
  - Capacitance Deviation from Rated Value
  - Insulation Resistance
  - Voltage proof
  - Dissipation Factor
  - Short / Open Circuit
- Marking

These steps are partly subcontracted
Soft-Winding Technology: Winding and Pre-Flattening
Various Winding Constructions 1

- **Single Design - Single layer**
- **Dual Section (series) Design - Single layer**
- **Film Foil**
- **Single Design – Multi-layer dielectric**
Various Winding Constructions 2

**Single Design - double metalized, single layer dielectric**

**Dual section (series) Design - double metalized, single layer dielectric**

**Triple section (series) Design - double metalized, single layer dielectric**

**Dual section (series) Design - Foil /metalized, multi-layer dielectric**
## Dominant Film Types*

<table>
<thead>
<tr>
<th>Film</th>
<th>Code</th>
<th>Best Tol. (±%)</th>
<th>ΔC -25°C to 85°C</th>
<th>Aging (%/yr)</th>
<th>DF (Typ)</th>
<th>Max. Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>polypropylene</td>
<td>PP</td>
<td>1</td>
<td>3%</td>
<td>0.2</td>
<td>0.05%</td>
<td>105</td>
</tr>
<tr>
<td>polyethylene terephthalate</td>
<td>PET</td>
<td>5</td>
<td>5%</td>
<td>0.4</td>
<td>0.50%</td>
<td>140</td>
</tr>
<tr>
<td>polyethylene naphthalene</td>
<td>PEN</td>
<td>5</td>
<td>5%</td>
<td>0.4</td>
<td>0.48%</td>
<td>155</td>
</tr>
<tr>
<td>polyphenylene sulfide</td>
<td>PPS</td>
<td>2</td>
<td>0.5%</td>
<td>0.3</td>
<td>0.20%</td>
<td>260</td>
</tr>
</tbody>
</table>
Capacitance vs. Temperature

-50    -25        0        +25  +50            + 75           +100          +125

Polyester PET
Polyester PEN
Polycarbonate
Polypropylene
Polyphenylene sulphide
Capacitance vs. Frequency

![Diagram showing capacitance variation with frequency for different capacitor types: Z5U, PC, PP, PPS, PET, NP0, X7R, Ta, NP0. The horizontal axis represents frequency in Hz, ranging from $10^2$ to $10^5$. The vertical axis represents the change in capacitance ($\Delta C/C\%$), ranging from -3 to +3.]
Capacitance vs. DC Voltage

- Al electrolyte
- all polymers
- NP0 ceramics
- Tantalum
- X7R ceramics
- Z5U ceramics
ESR vs. Temperature

PP

PEN

PET

PPS

Temperature (°C)

R Multiplier

Measured

1st Poly

2nd Poly

Temperature (°C)

R Multiplier

Measured

1st Poly

2nd Poly

Temperature (°C)

R Multiplier

Measured

1st Poly

2nd Poly

Temperature (°C)
EMI Suppression Requirements
Safety Caps – AC Part of SMPS

Mains network and electronic equipment EMI suppression applications:
• SMPS for home electronics including PCs, TVs, game consoles etc
• SMPS for office equipment
• Industrial and household appliances/white goods
• Lighting ballasts

General Requirements:
Life expectancy: >10 years (150k hours)
Rated voltage: 120 to 760 Vac
Transient voltage robust: High dv/dt (peak)
Self-healing
Safety standards:
  - IEC 60384-14
  - EN 60384-14 (ENEC)
  - UL 60384-14

The standards are globally practically identical, also China (CQC) uses the IEC standard

Capacitor Function:
EMI / RFI suppression
Capacitance Stability Example
Comparison of Different X2 Types

Test in outdoor conditions continuously in a Nordic country

Normal mains connected (240 VAC)

Each x-axis point means 2 000 hours elapsed time (13 x 2 000h = 26 000h ≈ 3 years)

Note: Y-axis scales vary!

% Change in Capacitance:
- Minimum negative
- Average negative
- Maximum negative
Capacitors in Series with Mains

**Capacitor Function:**
Capacitors are sometimes used in voltage dividers, called also capacitive power supplies, which is a simple way to power certain circuits directly from mains. Typically: 10-820nF / 275 – 300Vac

- Capacitors are used **in series** to the line before Zener diodes.
- The application often requires relatively stable capacitance value during long life time, even up to 15 year life.
- This application **does not need** a X2 capacitor, but often they are used.
EMI Suppression Capacitors
In-Series with mains

<table>
<thead>
<tr>
<th>Operating Voltage</th>
<th>Series</th>
<th>Safety agency approvals?</th>
<th>Max. Temp °C</th>
<th>Min. µF</th>
<th>Max. µF</th>
<th>Dielectric</th>
<th>Self healing?</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>275VAC</td>
<td>PME271M</td>
<td>X2</td>
<td>110</td>
<td>0.001µF</td>
<td>0.6µF</td>
<td>Impregnated Paper</td>
<td>Yes</td>
<td>Vacuum impregnated paper gives the best long-term stability</td>
</tr>
<tr>
<td>300VAC</td>
<td>PME271E</td>
<td>X1</td>
<td></td>
<td>0.01µF</td>
<td>0.22µF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>440VAC</td>
<td>R47</td>
<td>X2, X1</td>
<td></td>
<td>0.0047µF</td>
<td>2.2µF</td>
<td>Polypropylene</td>
<td></td>
<td>2-section series construction</td>
</tr>
<tr>
<td>520VAC</td>
<td>R47 (520V)</td>
<td>X2</td>
<td>85</td>
<td>0.0047µF</td>
<td>2.2µF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>275VAC</td>
<td>PHE820M</td>
<td></td>
<td>100</td>
<td>0.01µF</td>
<td>2.2µF</td>
<td>Polyester</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300VAC</td>
<td>PHE820E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300VAC</td>
<td>R60 3</td>
<td>No</td>
<td>105</td>
<td>0.15µF</td>
<td>6.8µF</td>
<td></td>
<td></td>
<td>Single-section with humidity protection</td>
</tr>
<tr>
<td>230 and 250VAC</td>
<td>R75 2 - R75 L</td>
<td></td>
<td></td>
<td>0.01µF</td>
<td>10µF</td>
<td>Polypropylene</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- New KEMET **F862** Series
Catastrophic Failures

• Fire as a consequence of dielectric break-down.
• Fire as a consequence of bad contact between wire, end spraying and electrodes.
• Short circuit of Y capacitor and a risk of exposing someone to dangerous electrical shock.
Surges on the Mains Network, UNIPEDE report

Field measurements have been behind the determination of test voltage levels for different capacitors.

UNIPEDE = Union of Producers and Distributors of Electric Energy
Because of the potential for injury the various safety agencies provide testing and recognition for X and Y capacitors.

<table>
<thead>
<tr>
<th>Region</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>Across-the-line EMI Filter</td>
<td>EN/IEC 60384–14</td>
</tr>
<tr>
<td>USA</td>
<td>Across-the-line EMI Filter</td>
<td>UL 60384–14 and CAN/CSA–E60384–14</td>
</tr>
<tr>
<td>Canada</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td></td>
<td>GB/T 14472</td>
</tr>
</tbody>
</table>

“Safety agency approvals do not insure product performance. Simply stated, equipment may fail after a line transient provided it fails safely.”
### EMI Capacitors
**X & Y Sub-Class Capacitors**

<table>
<thead>
<tr>
<th>Sub Class</th>
<th>Peak Voltage Test (KV) C ≤ 1μF</th>
<th>Peak Voltage Test (KV) C ≥ 1μF</th>
<th>Insulation / Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>8</td>
<td>-</td>
<td>Double or Reinforce Insulation</td>
</tr>
<tr>
<td>Y2</td>
<td>5</td>
<td>-</td>
<td>Basic or Supplementary insulation</td>
</tr>
<tr>
<td>X1</td>
<td>4</td>
<td></td>
<td>High Pulse Applications</td>
</tr>
<tr>
<td>X2</td>
<td>2.5</td>
<td></td>
<td>General Purposes</td>
</tr>
</tbody>
</table>

**Impulse**

- t
- T1 = 1.2μs
- T2 = 50μs

**Endurance**

- U1
- U2
- 0.1s

**Active Flammability**

- 2.5kV (X2)
- 5.0kV (Y2)
- time
EMI Safety Capacitors
X & Y Film (Polypropylene)

- Zn/Al Metallization (R: 10 to 20 Ω/sq)
- Vac: 275, 310, 330, 440, 600, 760
- Available as AEC Q200 Certified (85°C / 85% R.H., 1,000h)

- Very Good Self-Healing (PP)
- Resistant Against Voltage Spikes
- Very Low Dissipation Factor & Dielectric Absorption
EMI Safety Capacitors
Single Layer Ceramic Disc Capacitors

- Compact
- Low cost
- Ceramic is not self-healing
- Y5U dielectric: relatively unstable capacitance
  - Temperature dependence, aging and AC/DC voltage bias
EMI Safety Capacitors
X & Y Metallized Impregnated Paper

Multi-Layer Impregnated Dielectric

Single Design

Series Design

• Zn Metallization (R: 2.5 Ω/sq.)
• VAC: 275, 300, 480, 500, 660

• High Dielectric Constant
• Excellent Self-healing
• High dv/dt (Transient Handling Capability)
• High Ionization Level (Resin)
• Stable Capacitance in Harsh Environment & Voltage Conditions.
**Metallized Film**

*Self-Healing*

- Metal layer \(< 0.02\mu m\)
- Breakdown Channel
  - Weak Point
- Metallization Evaporates
  - The Insulation Is Restored

- Dielectric \(1\mu m\)

**Benefits of Metallized Film**
- Smaller Size
- Higher C Value
- Higher Reliability
- Lower Cost
- Lower Weight
Film Capacitance Loss

- (1) Dielectric Defect
- (2) Trapped Air
- (3) Corona Discharge
- AC Field $\geq 240V_{AC}$
Film Capacitance Stability

Example: Capacitance & DF Change Trend

THB Test (85/85, 1,000 Hours)

Protection against severe ambient conditions is critical for Heavy Duty and In Series with the Main Applications.
Typical Winding Structures

- **electrode**
  - Impregnated metallized paper (Ex. PME271)

- **dielectric**
  - Heavy edge metallizing metallized plastic film (Ex. R46 and PHE840M/E)
  - Series design metallized plastic film (Ex. PHE820)
## Typical Data

<table>
<thead>
<tr>
<th>Capacitance max. (µF)</th>
<th>Ceramic</th>
<th>PP film</th>
<th>PET film</th>
<th>Impregnated paper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.022</td>
<td>40.0</td>
<td>2.2</td>
<td>0.68</td>
</tr>
</tbody>
</table>

| Dielectric constant   | High    | 2.2     | 3.3      | 5.3               |

| Dissipation factor (%, 1kHz) | 3.0 | 0.05 | 0.5 | 0.8 |

| Insulation resistance (GΩ) | 80 | 400 | 250 | 100 |

| Max dU/dt (V/µs) | 100 | 100 | 1000 |     |

| Dependence on temperature and voltage | High | Low | Low | Low |

---

The Capacitance Company

KEMET

Charged™
Main Differences Between Technologies

• Metallized film and impregnated paper capacitors are self-healing and will survive a partial breakdown.
• Ceramic and film/foil capacitors cannot recover from a partial breakdown.
KEMET EMI Capacitor Range
Red Products are New KEMET Series

Increasing performance

Bridging Type of Insulation
- Basic or Supplementary
- Double or Reinforced

Transient Level (kV)
- 300 VAC
- 480 VAC
- 440 VAC
- 330 VAC
- 310 VAC/330 VAC (also + R)

660 VAC
- PME 264
- PME 271M
- PMR 209
- PZB 300
- R47
- F861
- PHE 820M/E
- PHE 840M/E
- R46
- PHE 846
- 1.43

760 VAC
- RC Circuit
- 440 VAC
- 760 VAC (600 VAC / UL)
- 480 VAC
- 440 VAC (480 VAC / UL)
- 330 VAC
- 310 VAC/330 VAC (also + R)

440 VAC
- PME 271Y
- PZB 300
- SMP 253
- F881
- PHE 850
- R41
- PMZ 2035
- PME 278
- F873
- PHE 845
- F872
- PHE 844
- F871
- PME 271E
- PMR 210
- PHE 841
- R49
- PME295

275 VAC
- 2xY2 + X2
- RC circuit
- 300 VAC
- 275 VAC/300 VAC
- 275 VAC/300 VAC (also + R)
- Insulated leads
- 275 VAC
- 275 VAC/300 VAC (also + R)

250 VAC
- RC circuit
- 300 VAC
- 275 VAC/300 VAC
- 275 VAC/300 VAC (also + R)

330 VAC
- 300 VAC
- 275 VAC/300 VAC
- 275 VAC/300 VAC (also + R)

RC  Circuit 440 VAC
- 440 VAC/520 VAC
- 310 VAC
- 275 VAC/300 VAC
- 275 VAC/300 VAC (also + R)
- Insulated leads 275 VAC
- RC circuit 275 VAC
- RC circuit 440 VAC
- 440 VAC
- 760 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
- 660 VAC
Customised: PMZ2074

- Application: Ignitors
- Metallized paper EMI suppressor, class X2
- Double capacitor; two capacitors in series
- Rated voltage 275 VAC
- Capacitances:
  - 150 + 47 nF
  - 220 + 82 nF
  - 220 + 100 nF
Customised: PHZ9004

- Low profile triple capacitor, three separate capacitors in the same box
- Metallized polypropylene EMI suppressor, X2 applications, 300 VAC
- Capacitances
  - 3 x 1.0 µF
  - 3 x 2.2 µF
  - Other values possible!
**RC units**
PMR205, PMR209, PMR210, PMZ2035

- Metallized Paper capacitor with integrated resistor
- Bipolar, suitable for DC and AC operations
- One component instead of two
- Small dimensions
- Outstanding reliability, high dU/dt capability and excellent self-healing properties
• Separate Polypropylene capacitor and resistor
• 10 nF to 1 µF / 1000 Ω - 10 Ω
• Series without safety approvals (250 Vdc/160 Vac – 630 Vdc/220 Vac)
• 275 Vac with X2 Class approval
Designed for use in applications for:

- Spark suppression during switching
- Transient suppression for protection of low-frequency thyristors and triacs
- $dU/dt$ limitation in thyristor and triac low-frequency snubber circuits
Why KEMET EMI Suppression Capacitors?

The main arguments for using KEMET EMI suppression capacitors are quality and performance and this is what we are selling:

- The highest possible safety regarding active and passive flammability.
- Excellent self healing properties
- Good resistance to ionization
- High $dU/dt$ capability
- Meets the most stringent IEC humidity class, 56 days
- Outstanding reliability in continuous operation
- Small dimensions
- Meets or exceeds various safety standards: EN/IEC 60384-14, UL1414...
- Is the reference for benchmarking

These benefits are the result of more than 60 years of dedicated research and development and are our customer’s safety insurance free of charge.
### Comparison of Dielectric Materials for EMI Capacitors

<table>
<thead>
<tr>
<th></th>
<th>MP</th>
<th>PP</th>
<th>PET</th>
<th>Ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transient capability</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Self healing capability</td>
<td>+++</td>
<td>++</td>
<td>+</td>
<td>– –</td>
</tr>
<tr>
<td>dU/dt</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>+++</td>
<td>+</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Stability</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>–</td>
</tr>
<tr>
<td>Soldering</td>
<td>+++</td>
<td>+</td>
<td>++</td>
<td>–</td>
</tr>
<tr>
<td>Reliability/Safety</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Performance/Volume</td>
<td>+++</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Component price</td>
<td>–</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Rating</td>
<td>22</td>
<td>15</td>
<td>13</td>
<td>4</td>
</tr>
</tbody>
</table>
# KEMET EMI Filters

## General catalogue articles

<table>
<thead>
<tr>
<th>Type</th>
<th>Ratings</th>
<th>Config.</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power feed through</td>
<td>16-800A, 250-440Vac</td>
<td>Pi,C</td>
<td>film, toroids</td>
</tr>
<tr>
<td>Small signal F/T</td>
<td>0.5-16A, 50-630Vdc</td>
<td>Pi,T,L,C</td>
<td>film, cer, toroids</td>
</tr>
<tr>
<td>Industrial</td>
<td>1-2500A, 250-600Vac</td>
<td>various</td>
<td>film, inductors</td>
</tr>
<tr>
<td>PCB</td>
<td>0.5-16A, 250Vac</td>
<td>various</td>
<td>film, toroids</td>
</tr>
<tr>
<td>Screen room</td>
<td>1-225A, 277Vac, 600Vdc</td>
<td>various</td>
<td>film, toroids</td>
</tr>
<tr>
<td>Cylindrical</td>
<td>6-16A, 275Vac</td>
<td>various</td>
<td>film, toroids</td>
</tr>
<tr>
<td>IEC Inlet</td>
<td>1-16A, 250Vac</td>
<td>various</td>
<td>film, toroids</td>
</tr>
</tbody>
</table>
Product Portfolio
Self Healing
Self-healing

Capacitor’s cross section:

In the case of dielectric breakdown, high current flows between the electrodes, through the discharge path:

Due to the high current, the dissipated power in the breakdown increases the temperature in the range of thousands of centigrade.

At this temperature, the two electrodes and the dielectric, evaporate as single atoms.

As soon as the temperature decreases, atoms combine with each other making new molecules.

These molecules are mainly gases made of Carbon (C), Hydrogen (H) and Oxygen (O).
Self-healing

After the phenomenon described above, the electric insulation has been restored (high insulation resistance):

In the case of excess Carbon (Carbon not combined with Hydrogen or with Oxygen), the excess amount will be deposited in the area where the breakdown has occurred, lowering the insulation resistance.

If the excess amount is high (high amount of Carbon compared to Hydrogen and Oxygen), Carbon will be deposited as a thicker layer: as a consequence the insulation resistance will be lower.

The dissipated power in the breakdown area after the breakdown depends on this resistance according to:

\[ P = \frac{V^2}{R} \]

The lower the resistance the higher the power. If the resistance is low enough, the capacitor stays almost as short circuit, and/or the breakdown continues to total destruction of the capacitor.
Comparison between different materials:

<table>
<thead>
<tr>
<th>FILM</th>
<th>C</th>
<th>H</th>
<th>O</th>
<th>S</th>
<th>C/H*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPS</td>
<td>6</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>1,50</td>
</tr>
<tr>
<td>PEN</td>
<td>14</td>
<td>10</td>
<td>4</td>
<td>0</td>
<td>1,00</td>
</tr>
<tr>
<td>PET</td>
<td>10</td>
<td>8</td>
<td>4</td>
<td>0</td>
<td>0,75</td>
</tr>
<tr>
<td>PP</td>
<td>3</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0,50</td>
</tr>
<tr>
<td>Cellulose</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>≈ 0</td>
</tr>
</tbody>
</table>

* After all available Oxygen (O) in the Polymer has been consumed (combined with C to CO). Large C/H ratio means high amount of conducting Carbon.

The graph shows what follows:

- the worst material is PPS;
- the best material is Paper, PP of films;
- PET is better than PEN.
EMI Core and Flex Suppressor®

Design and Characteristics
EMI Cores and Flex Suppressor®
Electromagnetic Interference
Radiated vs Conducted

Source

Radiated

Target

Conducted
EMI Cores
Design and Characteristics
EMI Filtering
Effect of Using EMI Suppression

An EMI core is a passive electric component used to suppress high frequency noise in electronic circuits.
EMI Cores
Types

- Solid
- Snap-On
- “Snail-Shaped”

Cables connect to devices act as an antenna for the noise

EMI Core employ the dissipation of high frequency currents in a ferrite ceramic to build high frequency noise suppression devices

- Available for round and flat cables
- Nickel-Zinc (NiZn) for FM band range
- Manganese Zinc (MnZn) for AM band range
EMI Core
Defining Parameters

- *No inductance, no rated voltage needed*
- Round or flat cable
- Mounting versions
- Shape and dimension
- Diagrams shows impedance over frequency
- Number of turns can increase the impedance
EMI Core
Frequency Range

Depends on the material

Mn-Zn series vs Ni-Zn series $|Z| - f$ Characteristics (representative example)
(measurement condition: measured with same-dimension ring core)

- AM band range
- FM band range
- Ni-Zn series core
- Mn-Zn series core

Impedance (Ω)

Frequency (MHz)
Flex Suppressor®
Design and Characteristics
Electromagnetic Interference
Radiated vs Conducted

Source

Radiated

Target

Conducted
Flex Suppressor® Sheets

Overview

• **Definition**
  – A flexible polymer sheet with micro-magnetic foils
  – Attenuates or suppresses Electromagnetic and Radio Frequency Interferences (EMI/RFI)
  – It can also be used to improve magnetic signal transmissions and receptions

• **How does it work?**
  – The sheet absorbs the electromagnetic noises and converts them into heat
Flex Suppressor®
Permeability

- High Permeability ($\mu$) = Strong Magnetic Field
- High $\mu$ Materials Absorb EMI
- High $\mu$ Absorb and Re-shape Magnetic Fields

$$\mu = \frac{B_0}{H_0} \cos \delta - j \frac{B_0}{H_0} \sin \delta = \mu' - j \mu''.$$  
$$\tan \delta = \frac{\mu''}{\mu'},$$

$\mu' = \text{Inductance}$  
$\mu'' = \text{Magnetic Impedance (loss)}$
Flex Suppressor®
Noise Attenuation

Transmitted Attenuation

Coupling Attenuation

![Graphs showing transmitted and coupling attenuation](image-url)
Transmitted Attenuation Measurement Technique

Printed board (FR-4) 100mm x 100mm x 1.6mm
Sample 50mm x 50mm
Micro strip line
Zo = 50Ω
Network analyzer

Incident wave = Reflection S11 + Loss + Transmission S21

Higher loss is preferable Max 1.0

EFH Type

EFR Type
**Flex Suppressor® Sheets**

**Applications**

---

**For EMI**
- **Radiation (for EMI regulation)**
  
  Suppression of radiation noise from CPU/GPU, signal line, cable etc.

**For De-sense**
- **Wi-Fi (for internal interference)**
  
  Internal noise is interfering to Wi-Fi receiving sensitivity. Flex-suppressor improves desense.

---

**For ESD**
- Internal interference caused by ESD is a factor of false operation. Flex-suppressor improves this issue.

---

**For RFID**
- **NFC (RFID etc.)**
  
  NFC communication distance is enhanced by Flex-suppressor.

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**For Wireless Charging**
- Conversion efficiency is improved by using Flex-suppressor.

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**Magnetic Shielding**
EMI Core

**Typical application**

- Information and communication devices
- White goods
  - dishwasher, washing machines, microwave, air conditioner, refrigerator
- Location
  - inside systems on cable or wiring harness
  - cable or wiring harness going to PCB
  - around data & power cables

Cables attached to devices can act as an antenna that radiates noise.
Flex Suppressor® Sheets
Notebook PC DRAM Memory Example

- DDR2-800: Bus clock 400MHz × 6 times
- DDR3-1600: Bus clock 800MHz × 3 times
Flex Suppressor® Sheets
Shielding Materials and Radio Wave Absorbers

- Shielding materials reflect most of the transmitted waves causing internal interference
  - Typically Metal conductive materials

- Radio wave absorbers prevent reflections and transform the absorbed energy waves into heat

- Shielding materials and radio wave absorbers can be combined to minimize the transmitted and reflected waves of incoming noise signals
Cool Tools
For Purchasing Professionals

E2BF EASY TO BUY FROM

One WORLD  One Brand  One Strategy  One Focus  One Team  One KEMET
Capacitor Fundamentals
Ripple Current
Ripple Current

KSPICE Example: C1206C106K8RAC

Current and Voltage - C1206C106K8RAC @ 25°C with 0 VDC Bias

Max Current (ARMS)

Max Voltage (VRMS)

Frequency = 95.499 kHz
C1206C106K8RAC(I) = 6.976 A
C1206C106K8RAC(V) = 1.230 V
Why ESR is Important

Power Consumption (Heat)

\[ P = I^2 R \]

Lower ESR → Lower Power Losses → Higher Efficiency
Ripple Current
ESR Changes with Temperature

\[ P = I^2 R \]
Why ESR is Important

- Why ESR is important.
  - Power loss in cap is $I_{\text{rms}} \times I_{\text{rms}} \times \text{ESR}$
  - Simplified to $I_{\text{avg}}$ see below (loss a little higher with $I_{\text{rms}}$)

$$P_{\text{avg}} = 1A \times 1A \times 0.010\text{ohm} = 10\text{mw} \text{ (using 1A avg current)}$$

$$P_{\text{avg}} = 5A \times 5A \times 0.010\text{ohm} = 250\text{mw} \text{ (using 5A avg current)}$$

Lower ESR $\Rightarrow$ Lower Power Losses $\Rightarrow$ Higher Efficiency
Ripple Current
Temperature Rise

C1206C106K8RAC @ +25°C with 0 VDC

100kHz ARMS 23.45A
°C 69.78°C
VRMS 3.95V

+100°C
Frequencies:
5000 kHz
10,000 kHz
30,000 kHz
100,000 kHz
300,000 kHz

C1206C106K8RAC @ +25°C with 0 VDC

100kHz ARMS 23.45A
°C 69.78°C
VRMS 3.95V

+100°C
Frequencies:
Not Recommended above +70°C
Choosing Capacitors for Low Voltage DC

K-Sim (WebSPICE) Usage and Techniques
Common K-Sim Use Cases

- Finding impedance and ESR
- Finding capacitance and inductance
- Finding the maximum allowable ripple current
- Finding the temperature rise given ripple
- Finding effective capacitance when a bias is applied
- Finding and exporting the equivalent circuit model
- Exporting scattering parameters
- Finding combined impedance of multiple capacitors
- Comparing performance under multiple conditions
- Y-Value tracking and crosshair locking
K-Sim Basics

- K-Sim is located at ksim.kemet.com

The K-Sim homepage is the main starting point where the capacitor type is selected.

Each part family has a selection screen where the desired specifics for the desired part (i.e. capacitance, rated voltage, size).
Finding Impedance and ESR

• What is the impedance and ESR of C1206C154K2RAC at a frequency of 1MHz with a bias of 50V at 85°C?
What is the impedance and ESR of C1206C154K2RAC at a frequency of 1MHz with a bias of 50V at 85°C?

Select Impedance and ESR as Plot Type
Set Temperature to 85°C
Set Voltage to 50V
Move Crosshair to 1MHz
Get Data:
Z = 1.263Ω
ESR = 24.029mΩ
Finding Capacitance and Inductance

• What is the capacitance and inductance of T598D107M016ATE050 at 125°C with a 16V bias at 100kHz?
Finding Capacitance and Inductance

- What is the capacitance and inductance of T598D107M016ATE050 at 125°C with a 16V bias at 100kHz?

Change Plot to Capacitance and Inductance

Change Temperature to 125°C

Change Voltage to 16V

Move Crosshair to 100kHz

Get Data:
C(calc)=113.88μF
C(meas)=127.27μF
L(calc)=2.34nH
L(meas)=N/A
What is the maximum allowable ripple current for C1206G105K3RAC at 130°C and 3MHz?
What is the maximum allowable ripple current for C1206G105K3RAC at 130°C and 3MHz?

Change Plot to Current and Voltage
Set the Temperature
Move Crosshair to 3MHz
Get Data: I=9.963A V=412mV
How much will the temperature rise on T521X337M016ATE025 at 85°C and 8V bias at 2A and 500kHz?
Finding the Temperature Rise Given Ripple

- How much will the temperature rise on T521X337M016ATE025 at 85°C and 8V bias at 2A and 500kHz??

Change Plot to TempRise
Set Temperature
Set Voltage
Move Crosshair to 2A
Get Data: ΔT=10°C
How much capacitance is available with C0805C224K5RAC when 35V are applied?
Finding Capacitance With Applied DC Bias

- How much capacitance is available with C0805C224K5RAC when 35V are applied?

Plot: Capacitance vs. Vbias (DC)

Change Plot to Capacitance vs. Vbias(DC)

Move Crosshair to 35V

Get Data: Cap drops by 40.5%
What is the lumped circuit element model for T591X476M035ATE070 at 100kHz at 125°C?
Finding the Equivalent Circuit Model

- What is the lumped circuit element model for T591X476M035ATE070 at 100kHz at 125°C?

File Export

Instructions:
Please use the tabs below to select the model file format type.

The models are only accurate for the selected frequency. Only the S-parameter type is a broadband model. The models are exported at the frequency closest to the selection on the available data.
The “S2P Export” button exports both S21 and S11 parameters regardless of which scattering parameter plot is shown.

CKT	TXT	DAT	PRN	CIR

.SUBCKT T591X476M035ATE070 1 8
*Temp@ 25°C, Bias@ 17.5Vdc, Center Freq@ 100.000 kHz*
* KEMET Model RLC Tant5RC
L 1 1 2 2.92E-09
R6 2 8 2.13E+06
R1 2 3 9.50E-03
C1 3 8 1.52E-06
R2 4 3 3.22E-03
C2 4 8 3.03E-06
C3 5 8 6.06E-06
R5 6 3.22E-03
R4 5 6 3.22E-03
C4 6 8 1.23E-06
C5 7 8 24.26E-06

ENDS

Email T591X476M035ATE070.CKT

E-mail:
• How to determine the S-parameters for C0402C508K8GAC at 50Ω in series?
Exporting Scattering Parameters

- How to determine the S-parameters for C0402C508K8GAC at 50\(\Omega\) in series?

Change Plot to Sxx vs Freq.

Select Series

Click Export S2P
Finding Combined Impedances

• What is the combined impedance of multiple parts in parallel?
Finding Combined Impedances

- What is the combined impedance of multiple parts in parallel?

Select more parts
Enter quantity of parts
Combine Impedances

View Chart Data Hide Controls

Impedance and ESR - Combined @ 25°C with 1.25 VDC Bias

Part Numbers:
- C0201C103K8PAC[2]
- C0402C104K8PAC[2]
- C0603C105K8PAC
- T520X108M2R5ATE010

Controls and Parameters:
- Multiple Part Numbers
- Temperature Max: 85°C
- Bias Voltage Max: 2.5 V
- Power Temp Rise
- External Resistance
- External Inductance

Enable Y-Value Tracking
- Enabled
- Combine Z

Add Another Part Number
Multiple Voltages and Temps
Comparing Performance Under Multiple Conditions

• How do the impedance and ESR of C1812G105K5RAC change over temperature?
Comparing Performance Under Multiple Conditions

- How do the impedance and ESR of C1812G105K5RAC change over temperature?

Click the “Multiple Voltages and Temps” button

Use the “+” to add conditions

Enter the desired conditions
Y-Value Tracking and Crosshair Locking

• Use dropdown box to select which Y-Value the crosshairs will track.
• The crosshair will retain their locked position even when changing plots.
Thank you

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