Aluminum Electrolytic Construction and Materials
Construction of Alum. Electrolytic

Rolled Foil

Spacer (Electrolyte)

Aluminum (oxidized) (Anode)

Aluminum (Cathode)

Spacer (Electrolyte)
Capacitance = \( K \times \frac{A}{t} \)

where:
- \( A \) = Surface Area
- \( t \) = dielectric thickness

Diagram: Aluminum Untreated Surface Area

- Anode Plate
- Cathode Plate
- Dielectric
- Electrolyte

Capacitance formula applied to the diagram.
Electrolyte Capacitance = K x A / t

Anode Plate

Dielectric

Cathode Plate

Aluminum Acid-Etched Surface Area
Forward bias is same as formation bias. If dielectric gets thin enough, the forward bias voltage will form new dielectric (thinner than original because $V_{\text{Formation}} > V_{\text{Rating}} > V_{\text{Application}}$).

Reformed dielectric region.
Rolled foil is inserted in can, and sealed.

Lead extensions allow electrical contact to foil plates.

Liquid electrolyte fills can.
Liquid Electrolyte fills can

Sealing Material

Rolled Foil Element
### Aluminum Catalogs (Ripple/ESR):

#### RMS Ripple Current mA (85°C, 120 Hz)

<table>
<thead>
<tr>
<th>WVDC</th>
<th>6.3</th>
<th>10</th>
<th>25</th>
<th>35</th>
<th>50</th>
<th>63</th>
<th>80</th>
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<td>125</td>
<td>135</td>
<td>125</td>
<td>95</td>
<td>100</td>
</tr>
</tbody>
</table>

**Also:**
- Ripple Current Multipliers
- up to 10 KHz
Alum. Elect. Temperature Sensitivity

Capacitance (C/Co where Co=Capacitance at 20°C)

- **High Voltage**
- **Low Voltage**
100 uF Z vs Freq vs Temp

SMT AL-Elect. 100 @ 6.3

KEMET T491D107M006
100 uF ESR vs Freq vs Temp

SMT AL-Elect. 100 @ 6.3

KEMET T491D107M006
100 uF Cap vs Freq vs Temp

SMT AL-Elect. 100 @ 6.3

KEMET T491D107M006
RC Ladder Network

tc1 = C1 x R1

tc2 = C2 x (R1+R2)

tc3 = C3 x (R1+R2+R3)


tcn = Cn x (R1+R2+R3...+Rn)
\[ tc_1 = C_1 \times R_1 \]
\[ tc_2 = C_2 \times (R_1 + R_2) \]
\[ tc_n = C_n \times (R_1 + R_2 \ldots + R_n) \]

Electrolyte Resistivity

RC-Ladder in Aluminum Electrolytic
100°C Life Test 10uF @ 25VDC

Capacitance Shift (%)

Time (Hours)

Tantalum

Aluminum
100°C Life Test 10uF @ 25VDC

ESR (Ohms)

Time (Hours)
Leaky capacitors shorting circuits; problem spreads

BY ED SPERLING

Failing capacitors are sending shock waves up the electronics food chain—literally. PCs are crashing and televisions and camcorders are going on the fritz, and the problem is becoming more widespread, according to those who replace those components.

At the heart of this controversy are low-ESR aluminum electrolytic capacitors, all of which were made in Taiwan. According to systems integrators who build custom PCs and those who repair them, the capacitors start leaking electrolytic fluid within days or weeks after the computer is turned on. In most cases, the leaking fluid causes short circuits. Less commonly, they actually explode.

Carey Holzman, a private-label white-box PC builder in Glendale, Ariz., started noticing the problem about 10 months ago and has been contacting motherboard vendors to get them to acknowledge and fix the problem. So far, no one is owning up to it.

“We would get strange errors in Windows and it wouldn’t reboot, or the board would lock up and reboot randomly,” said Holzman, who has been building PCs for the past 12 years. “The boardmakers were telling me it was either the power supply or heat. But I started noticing leaking capacitors. The more leaks, the more problems they showed. And the longer you wait, the worse the problem gets.”

Holzman is far from alone in issuing warnings. In fact, entire news groups have sprung upon the Internet to deal with this matter, and many of them are naming names and

[Continued on page 6]
Leaky Al-Electrolytics (board Oct. 2003)
Aluminum “V” Chip

Anode (Aluminum)

Cathode (Aluminum)

Dielectric (Anodized Aluminum)

Solid-State Polymer Electrolyte
Film Capacitors

Construction and Materials

KEMET

CHARGED.
Film Capacitors utilize two main constructions:

- **Multilayer Construction**: Uses multiple layers of film and metalized pattern.
- **Rolled Foil Construction**: Consists of thin foil, film, and thin foil layers rolled together.

These constructions provide high capacitance and good stability in electronic circuits.
Capacitance Change vs. Temperature

% Capacitance Change

Temperature (°C)
%DF vs. Temperature

Dissipation Factor (%)

Temperature (°C)

Film DF Temperature Dependence
Foil
- Thicker Electrode Plates
- Lower ESR
- Less "Self-Healing"
- Easier Moisture Ingress

Metalized
- Sputtered Electrode on Film
- Very thin electrodes
- Higher ESR
- Efficient "Self-Healing"
- Retards moisture ingress
- Low Current / Low Overvoltage
Current into fault (crack)

Electrodes = Sputtered (CVD) Aluminum

Fault (Crack)

Electrode open (fused) at high current site

Fault (Crack)
Web pattern to improve fusing

‘Neck-down’
Current fuses Al plate material - capacitance loss with time
Ceramic Capacitors

Construction and Materials
Multilayer Construction

"Tape" process involves a ceramic sheet that is filled with plastic binders to allow handling.
Initial Ceramic Process - Slurry

1. **Powder Weigh**
2. **Pre-Blend**
3. **Milling**
4. **De-Air**
5. **Latex Addition**
6. **Slurry**
7. **Ceramic "Slurry"**
Squeegied Application of Ceramic Slurry

Glass Plate

Slurry Application

Drying Oven

Drying Oven

Squeegied Application of metal ink

Stop when required layer count is met.
Agglomerates are lumps that form in the deposited ink as metal particles coagulate to one area, or are dropped from screen.

Agglomerates can cause shorts or lead to "weak" spots in the dielectric.
Tape process presses agglomerates down, and tape conforms to undulation.

Agglomerate defect creation is minimized.
Unsupported Ceramic "Tape" 10 to 50 microns
Ceramic Tape / Electrode / Transfer-Laminate
Tape & Film (‘KTP’ Process)

Hood

Hopper

Slurry Added

Film Reel Source

Hot Zone

Hepa Filters

Reelers

FIlm Reel with Ceramic

Supported Ceramic Deposit 0.5 to 5 microns
“KTP” Process

Carrier / Ceramic / Electrode / Transfer-Laminate
Typical Multilayer Ceramic Capacitor

- Silver/Copper
- Nickel
- Tin
- Ceramic Body
- Electrode Plate Layers
- End Termination
Calculation of capacitance:

\[ C = \frac{KA(n-1)}{t} \]

- **C** = Design Capacitance
- **K** = Dielectric Constant
- **A** = Overlap Area
- **t** = ceramic thickness
- **n** = number of electrodes
Relative Capacitance vs. Temperature

- Y5V
- Z5U
- X5R
- X7R
- NP0/C0G

K Magnitude vs. Temperature (°C)
Defines Temperature Characteristics

<table>
<thead>
<tr>
<th>Significant Figure of Temperature Coefficient</th>
<th>Multiplier added to Temperature Coefficient</th>
<th>Tolerance of Temperature Coefficient</th>
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<tbody>
<tr>
<td>PPM/°C</td>
<td>Symbol</td>
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NP0 not shown - old designation style

EIA Designations for Class 1

KEMET CHARGED:
# EIA Designation for Class 2 & 3

Defines Temperature Characteristics

<table>
<thead>
<tr>
<th>Low Temperature</th>
<th>High Temperature</th>
<th>Maximum Capacitance Change</th>
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<tr>
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</table>

Class 3

EIA Designation for Class 2 & 3

- X7R?
- X5R?
- Z5U?
- X5P?
- X8R?
- X8S?
- Y5V?
Voltage Coefficient – High ‘K’

Capacitance Change vs. DC Bias

% Change vs. Applied DC Bias (VDC)
Capacitance Change vs. DC Bias

-30%  -25%  -20%  -15%  -10%  -5%  0%  5%

Applied DC Bias (VDC)

-30%  -25%  -20%  -15%  -10%  -5%  0%  5%  10%  15%  20%  30%  40%  50%

50 WVDC Rated
0805 X7R 0.1 uF / 50 WVDC

Capacitance Change vs. Applied DC Bias (VDC)

- Manuf. 'A'
- Manuf. 'B'
- Manuf. 'C'
- KEMET

PME
BME
X7R Aging Rate of 1%/Dec-Hr

Percentage Nominal

<table>
<thead>
<tr>
<th>Time Post Heat</th>
<th>% Change</th>
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<tbody>
<tr>
<td>1 Hr</td>
<td>+11.4%, -8.0%</td>
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<tr>
<td>10 Hr</td>
<td>+10.3%, -8.9%</td>
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<tr>
<td>48 Hr</td>
<td>+9.5%, -9.8%</td>
</tr>
<tr>
<td>100 Hr</td>
<td>+9.1%, -10.7%</td>
</tr>
<tr>
<td>1 kHr</td>
<td>+8.12%, -11.6%</td>
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<tr>
<td>10 kHr</td>
<td>+7.0%, -12.5%</td>
</tr>
<tr>
<td>100 kHr</td>
<td>+5.9%, -12.5%</td>
</tr>
</tbody>
</table>
Y5V Aging Rate of 8%/Dec-Hr

Percentage Nominal:
- 1 Hr / +37.5%, -7.4%
- 10 Hr / +26.5%, -14.8%
- 48 Hr / +19.5%, -19.5%
- 100 Hr / +16.4%, -21.6%
- 1 kHr / +7.1%, -27.9%
- 10 kHr / -1.5%, -33.7%
- 100 kHr / -9.4%, -39%

Time Post Heat:
- 1
- 10
- 100
- 1,000
- 10,000
- 100,000
Unk Aging Rate of 22%/Dec-Hr
Electrode Plate
Length/Width/Thickness
Material Resistivity

Dielectric Resistance
Energy lost in aligning polarization to conform to field.

Interconnect between electrode and termination

Termination
Thickness/Height/Width
Material Resistivity
Plate-Material Resistivity

Pd-Ag Electrodes

Reference
Resistance vs. Aspect-Ratio

\[ R = \theta \times \frac{\text{Length}}{\text{Width} \times \text{Thickness}} \]

Aspect-Ratio = \frac{\text{Length}}{\text{Width}}
Plate Inductance

\[ L(nH) = 5l \left[ \ln\left(\frac{2l}{(W+T)}+1/2\right) \right] \]

Where:
- \( l \) = length in inches
- \( W, T \) = width & thickness (inches)

Aspect Ratio is controlling factor
1206 has higher ESL than 0612
Mutual Inductance controlling factors = Dielectric Thickness & Plate Count

Self-Inductance per Plate
Mutual-Inductance across plates.
ESL Elements of MLC

Lm  Mutual-Inductance
Ls  Self-Inductance
ESL changes with Frequency

Lower Frequencies
All plates active
Inductance - Cumulative

Higher Frequencies
Lower plates Active
Upper plates inactive
Inductance – minimum loop
Flex Testing

with

Capacitance Monitoring

KEMET Electronics Corp.
What is a "Flex Crack?"

- Ceramic Chip
- Termination
- Crack
- Solder
- SMT Pad
Crack occurs at delineation site - stress gradient

Ceramic in expansive mode

Ceramic held rigid by termination
ESD Susceptibility

Determined by Test

Reference Capacitor Charged
Reference Capacitor Discharges into Test Capacitor

Source or Initial Capacitance

CUT (Capacitor Under Test)

Pass / Fail determined by Capacitance and Insulation Resistance Tests
Q_{\text{Initial}} = \text{Cap}_{\text{Source}} \times \text{Voltage}_{\text{Initial}}
Q = 150 \text{ pF} \times 8 \text{ kV} = 1.2 \times 10^{-6} \text{ Coulombs}

Q_{\text{Final}} = Q_{\text{Initial}} \text{ or simply } Q
1.2 \times 10^{-6} \text{ Coulombs} = 1.2 \times 10^{-6} \text{ Coulombs}

\text{Voltage}_{\text{Final}} = \frac{Q}{(\text{Cap}_{\text{Source}} + \text{Cap}_{\text{CUT}})}
V = \frac{1.2 \times 10^{-6}}{(150 \text{ pF} + 1000 \text{ pF}) \times 10^{-6}} = 1043 \text{ V}
Why MLCs are susceptible

• Charge transfer is only significant for lower capacitance values (<0.01uF)
• This capacitance range is dominated by ceramics
• Downsizing (0603, 0402, 0201) requires thinner dielectric
  ▪ Lower breakdown voltages
  ▪ Higher voltage coefficients/lowers capacitance
Piezoelectric Noise

Mechanical forces can create electrical signals.

Electrical forces can create mechanical distortion.

Ceramic Chip

Barium Titanate crystal cartridges
Piezoelectric Dos and Don’ts

• Do Not
  ▪ Use in audio circuits where signal levels are high (final stages).
  ▪ Use in high-gain circuits where mechanical shock or vibration can create noise.
  ▪ Use in audio front end where mechanical shock or vibration can create noise.
  ▪ Use in bus applications that are being cycled on and off in a ‘sleep’ mode.

• Do use
  ▪ In high frequency circuits where response of ceramic is too slow for matching electrical stress with mechanical response (>40 kHz)
  ▪ Use leaded (or leadframe) ceramics to allow mechanical isolation between chip and board.
  ▪ Use higher voltage rating, or lower dielectric constant to diminish response (both of these could lead to larger chips).
Tantalum Capacitors

Construction and Materials
Tantalum Process

1. Powder
2. Press
3. Sinter
4. Formation
   - Impregnation
   - $\text{Mn(NO}_3\text{)}_2$
5. Counter electrode
6. C + Ag
7. Oven
8. Assembly
9. Encapsulation
10. Testing
Pressed Pellet - tantalum in chance contact, most not in contact

- Tantalum Wire
- Tantalum Particles
- Die Cavity Volume
Sintered Pellet - All tantalum in electrical contact

Tantalum Wire

Tantalum Particles

Die Cavity Volume
Dielectric Formation

Interconnected Tantalum Particles

$\text{Ta}_2\text{O}_5$ Dielectric Layer
Interconnected Tantalum Particles

MnO$_2$ Impregnation

Surrounds Ta$_2$O$_5$

Ta$_2$O$_5$ Dielectric Layer

MnO$_2$ Penetration into Channels
Tantalum Construction

- Interconnected Tantalum Particles
- Carbon
- Silver
- Ta$_2$O$_5$ Dielectric Layer
- MnO$_2$ Penetration into Channels Surrounds Ta$_2$O$_5$
Healing Effect of MnO₂ Layer

Crack

Nickel

Ta

MnO₂

Mn₂O₃

Ta₂O₅
Tantalum RC-Ladder

Surface Silver Termination

\[ tc_1 = C_1 \times R_1 \]
\[ tc_2 = C_2 \times (R_1+R_2) \]
\[ tc_n = C_n \times (R_1+R_2...+R_n) \]
RC Ladder Network

- \( t_{c1} = C_1 \times R_1 \)
- \( t_{c2} = C_2 \times (R_1 + R_2) \)
- \( t_{c3} = C_3 \times (R_1 + R_2 + R_3) \)
- \( t_{cn} = C_n \times (R_1 + R_2 + R_3 + ... + R_n) \)
Solid Tantalum Surface-Mount Capacitor

- MnO₂ / Ta₂O₅ / Ta
- Silver Adhesive
- Silver Paint
- Washer
- Leadframe (- Cathode)
- Leadframe (+ Anode)
- Carbon
- Tantalum Wire
- Weld
Oxygen, pulled into Ta by applied voltage, combines with tantalum to form Ta$_2$O$_5$

Thickness determined by the formation voltage.

$\sim$20Å per Volt

Formation Voltage

= 3x to 4x Rated Voltage
Although polarity is the same as in formation, the voltage is much less and although no additional oxygen transfer takes place, the oxygen continues to be locked into the $\text{Ta}_2\text{O}_5$ bond.
When force (voltage) is reversed & high enough (*knee voltage*), oxygen displacement begins, leaving tantalum behind.

Reversed Biased
Although polarity is the same as in formation, the voltage is much less and although no additional oxygen transfer takes place, the oxygen continues to be locked into the Ta$_2$O$_5$ bond.
Knee Voltage Determination

T491X337M010 #1

Leakage Current (20Sec) vs. Applied DC Voltage

Knee voltage

15% Rated Voltage
@+25°C
“Normal”
# 83

**Catalog Table**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Maximum Reverse Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°C</td>
<td>15%</td>
</tr>
<tr>
<td>85°C</td>
<td>5%</td>
</tr>
<tr>
<td>125°C</td>
<td>1%</td>
</tr>
</tbody>
</table>
T520V686M006 @ 25°C

Applied DC Voltage (20 sec)

Measured Current (uA) vs. DC Voltage

I(uA) = 70.55 x VDC + 110.12
RR = 99.8%
KneeV = 15.6%Vr
Knee Voltage Determination +85°C

T520V686M006 @ 85°C

I(uA) = 91.52 x VDC + 125.31
RR = 99.9%
KneeV = 14.7%Vr
Knee Voltage Determination +125°C

T520V686M006 @ 125°C

\[ I(uA) = 89.97 \times VDC + 104.95 \]

RR = 100%
KneeV = 11.7%Vr
Applied DC Voltage

Resultant Current (μA)

“Periodic Application” (-6.5VDC)

“Normal Knee” -15%Vr (-5.3VDC)

Xint = -1.90 vdc (5.4% Vr)

y = 11.96x + 22.21, rr=99.92%
Breakdown Mechanism
Differences in coefficients of thermal expansion cause stresses to build up within the structure, the mold compound tries to pull (shear) the capacitor apart!
Edges and corners are focal points of shrinkage forces. Crack can develop in pellet that fractures Ta$_2$O$_5$ dielectric sites. Full power application results in ignition - not self-healing.
Scintillations
Initial Variable Breakdown Levels

Post 100% Electrical Test

Breakdown Relationship to Crack Severity

Scv @ 250%Vr
Scv @ 200%Vr
Scv @ 150%Vr

Ta Ta₂O₅ MnO₂
NEW Breakdown Relationship to Crack Growth

Post Solder Breakdown Levels

Scv @ 150%Vr
Scv @ 75%Vr
Scv @ 25%Vr

Ta Ta₂O₅ MnO₂
Raw Distribution includes pieces below Screen Limit

Pre-screen Distribution

Breakdown Voltage

100% Screen Limit
100% Screen eliminates Distribution below Limit

Breakdown Voltage

100% Screen Limit
Forces create new, altered distribution after solder.

New Distribution now includes Pieces BELOW Limit

Original Distribution

Process (Solder) Changes Distribution -- adds Variation - lowers mean.

Application Voltage

100% Screen Limit

Breakdown Voltage

Voltage Derating
Recommended IR Reflow Profile (with Pb)

- Time (Seconds): 0, 50, 100, 150, 200, 250, 300
- Temperature (°C): 0, 50, 100, 150, 200, 250, 300
- Temperature Changes:
  - 2°C/sec from 0 to 60 Sec.
  - 2°C/sec from 240°C to 300
  - 2°C/sec from 300 to 240°C
  - 2°C/sec from 240°C to 200

- Time Markers:
  - 60 Sec.
  - 90 Sec.
  - 95 Sec.
  - 5 Sec.
  - 45 Sec.
  - 45 Sec.
Recommended Pb-Free IR Reflow

Temperature (°C)

Time (Seconds)

25-50 Sec.  260°C

3ºC/sec

90 Sec.

135 Sec.

55 Sec.

55 Sec.

3ºC/sec

3ºC/sec

60 Sec.

50

100

150

200

250

300
An attempt to exercise the package expansion/contraction prior to customers solder process.
Proofing Procedure

- Establish a voltage capability of the capacitor through a high resistance.
  - 1 kOhm resistor most common
  - Apply highest voltage that capacitor will ever see.
  - Verify voltage at capacitor.
  - Remove the voltage.
- Remove the resistance - no longer necessary.
- Capacitor has been “proofed.”
Conclusions

• The 100% electrical testing of these devices does not preclude faults from developing within the device.
• The mismatch of CTEs for the materials used in these devices can create forces large enough to create new cracks or extend existing cracks during the solder process.
• The severity of the solder process will have a direct impact to the magnitude of power-on failures.
• The voltage capability of the device is defined by the level of stress applied to the part after mounting (proof).
• The closer the peak application voltage is to the rated voltage of the part, the greater the number of turn-on failures.
Moisture Problems

Case Absorption

Ionic Penetration
Plastic moisture absorption

Moisture absorbed into plastic material over long time periods. Plastic is **hydroscopic**.
Pressure venting at egress

Pressure builds and may create crack.
Pressure vents along lead egress.
Jet is deflected down, then into glue-pad at bottom of chip.
Jet turns outward to sides of chip.

?Crack?
Gas jets at sides

Jets of gas emanate from beneath chip and can displace small component or solder balls if close enough.
Good MnO$_2$ Coverage

"Necked down" channel

Thin MnO$_2$ Coverage

"Un-healed" faults
Ionic laden moisture establishes contact to fault -- No MnO₂ healing mechanism!
Ag⁺ ions move freely into channel along C/MnO₂

Ag⁺ ions restricted from channel by "Blockers"
Aluminum (WET) Failure Modes

- Reverse polarity damage
- Solder heat evaporation of electrolyte (wet)
- Cleaning solvent susceptibility
- Leakage increase
  - Outgassing
  - Loss of electrolyte
  - Drying
- Early Catastrophic Failures
- Increasing DF, ESR, Z
- Shelf Life loss of memory
  - Requires "Refresh"
  - Low voltage applications create "shelf life"
Film Failure Modes

- **Sensitive to mild overstress (surge voltage)**
- **Foil type**
  - ✔ Short Circuits
  - ✔ Increasing ESR with temp/time
- **Metalized Electrodes**
  - ✔ Self-healing / noise generation
  - ✔ Loss of cap / open circuits
  - ✔ Parametric degradation with life
  - ✔ Surge susceptibility
  - ✔ Aluminum attacked by moisture
Ceramic Failure Modes

❌ No wear-out mechanisms of undamaged part

❌ Sensitive to mechanical damage

❌ Crack induced failures
  ✓ Short Circuits / Catastrophic
  ✓ Increasing Leakage / degradation of IR
  ✓ Increasing ESR / DF
Tantalum (Poly-Al) Failure Modes

- Sensitive to mild overstress (surge), reverse polarity
- No wear-out mechanisms / self-healing
- Stress induced failures
  - Short Circuits / Catastrophic
  - Increasing Leakage / degradation of IR
  - Increasing ESR / DF
  - Capacitance decay
- Plastic package hydroscopic venting during reflow disturbing smaller adjacent components (0603 chips)