Ripple Voltage & ESR

Powering Integrated Circuits (ICs), and managing ripple voltage as it relates to ESR of capacitors

• Low voltage ICs require supply voltage (Vcc) to have reduced levels of ripple voltage

• Low ESR capacitors, such as solid polymer, hybrid and high cap ceramic chip (MLCCs) are used in combination to minimize ripple voltage in powering ICs
**Powering Advanced Electronics**

- Electronic products require power to operate
- Sources of the power can be from AC line (from *electric utilities*), Green Power (wind and solar) or from batteries
- Integrated circuits (ICs) are used in virtually all electronic equipment and have revolutionized the world of electronics & digital appliances
- This presentation looks at the requirements of capacitors used to power **Integrated Circuits (ICs)**

**Advances & Trends in Integrated Circuits**

Among the most advanced high speed integrated circuits are microprocessors or "cores", which control everything from computers, servers and cellular phones to digital microwave ovens.
Ripple Voltage & ESR

*Powering Advanced Electronics*

- Converting **AC Line Voltage to DC Voltage**
- Goal is to convert as efficiently as possible and provide clean & steady DC voltage (**Vcc**) to power integrated circuits

![AC-DC Converter, Switched Mode Power Supply Diagram]
Powering Advanced Electronics

- **DC to DC converters** are important in sub subsystems and in portable electronic devices, which are supplied with power from batteries.
- Such electronic devices often contain several **sub-circuits**, each with its own \((Vcc)\) voltage level requirement often **different from that supplied by the battery**.
- Additionally, the battery voltage declines as its stored power is drained.
- DC to DC converters maintain (regulate) steady voltage \((Vcc)\) to ICs from a decreasing battery voltage.
**Ripple Voltage & ESR**

**DC Voltage (Vcc)**

**Ripple Voltage** - Small unwanted residual periodic variation of the direct current (DC) output of a power supply.

Ripple voltage is undesirable in many high speed electronic circuit applications (such as ICs):

- Within digital circuits, ripple voltage reduces the threshold at which logic circuits give incorrect outputs and data is corrupted.
- Undesired noise in audio & video ICs.
Ripple Voltage & ESR

Power supply design for high-speed devices can often drive the need for low noise, low ripple voltage rails. ... high-speed devices require the control of output voltage (Vcc) ripple and noise in order to fully maximize their performance. ... Typically VCC ripple and noise requirements can range from 5-100mV (0.005V ~ 0.100V) [i.e. very low levels] – See Figure 1 Below

When designing any switch-mode power supply (SMPS), including a power module, it’s important to select output capacitors for minimizing voltage ripple. For many SMPS, this means selecting a sufficient amount of output capacitance with low ESR (effective series resistance). Voltage ripple is a function of the inductor ripple current, the switching frequency (FSW) and the output capacitor’s ESR. Therefore, minimizing the ESR in the output capacitors will minimize the output voltage ripple.

Figure 1
**Equivalent Series Resistance (ESR) of Capacitors**

Capacitors are needed for storage and smoothing of DC output (Vcc) of power supplies and converters.

- The equivalent series resistance or ESR of a capacitor is particularly important in power supply designs.
- When analyzing a circuit, a capacitor should be depicted as its equivalent circuit including the ideal capacitor, but also with its series ESR value (*show in Figure 2 below*).

\[
V = I \times R \\
\text{Ripple Voltage} = I \times \text{ESR}
\]

*To reduce ripple voltage, circuit designers must use capacitors with Low ESR*

---

**Figure 2**

**Electrolytic Capacitor**
- Polarized
- Type: Aluminum & Tantalum

**Electrostatic Capacitor**
- Non-Polarized
- Type: Ceramic & Film
Multiple Parallel Capacitors

- Multiple capacitors are typical wired in parallel connection (see Figure 3 below) to reduce ESR (and ripple voltage) and handle high current

\[
\frac{1}{ESR_{Total}} = \frac{1}{ESR_1} + \frac{1}{ESR_2} + \frac{1}{ESR_3} + \frac{1}{ESR_4}
\]

Ripple Voltage = \( I \times ESR_{Total} \)

Example: \( ESR_1 = ESR_2 = ESR_3 = ESR_4 \ldots \) All = 0.120 Ω (120mΩ)

\( ESR_{Total} = 0.030\Omega \) (30mΩ)

Ripple Voltage @ 1A = 0.030V (30mV)
## Ripple Voltage & ESR

### Capacitor Type Comparison: SMT / 100uF / 6.3V ~ 100VDC

Equivalent Series Resistance (ESR) & Ripple Voltage

<table>
<thead>
<tr>
<th>Capacitor Type</th>
<th>Size</th>
<th>Capacitance</th>
<th>Voltage Rating</th>
<th>100KHz ESR</th>
<th>Ripple Current Rating</th>
<th>Ripple Voltage @ 1000mA (1A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLCC / X5R Ceramic</td>
<td>1210 (3.2mm X 2.5mm)</td>
<td>100uF ±20%</td>
<td>6.3VDC</td>
<td>Not Specified</td>
<td>Not Specified</td>
<td>&lt; 0.005V</td>
</tr>
<tr>
<td><strong>Polymer (Solid)</strong> Aluminum Electrolytic</td>
<td>D (7343)</td>
<td>100uF ±20%</td>
<td>6.3VDC</td>
<td>≤ 0.010 Ω</td>
<td>3500mA</td>
<td>≤ 0.010V</td>
</tr>
<tr>
<td><strong>Hybrid Polymer</strong> Aluminum Electrolytic</td>
<td>6.3mm x 6.3mm</td>
<td>100uF ±20%</td>
<td>6.3VDC</td>
<td>≤ 0.036 Ω</td>
<td>1630mA</td>
<td>≤ 0.036V</td>
</tr>
<tr>
<td></td>
<td>6.3mm x 8mm</td>
<td></td>
<td>10VDC</td>
<td>≤ 0.035 Ω</td>
<td>1910mA</td>
<td>≤ 0.035V</td>
</tr>
<tr>
<td></td>
<td>8mm x 10.8mm</td>
<td></td>
<td>10VDC</td>
<td>≤ 0.018 Ω</td>
<td>1680mA</td>
<td>≤ 0.018V</td>
</tr>
<tr>
<td></td>
<td>8mm x 10.8mm</td>
<td></td>
<td>35VDC</td>
<td>≤ 0.030 Ω</td>
<td>1800mA</td>
<td>≤ 0.030V</td>
</tr>
<tr>
<td></td>
<td>10mm x 10.8mm</td>
<td></td>
<td>40VDC</td>
<td>≤ 0.015 Ω</td>
<td>1630mA</td>
<td>≤ 0.010V</td>
</tr>
<tr>
<td><strong>Polymer Cathode</strong> Tantalum Electrolytic</td>
<td>A (3216)</td>
<td>100uF ±20%</td>
<td>6.3VDC</td>
<td>≤ 0.024 Ω</td>
<td>2400mA</td>
<td>≤ 0.024V</td>
</tr>
<tr>
<td></td>
<td>B (3528)</td>
<td></td>
<td>6.3VDC</td>
<td>≤ 0.025 Ω</td>
<td>1844mA</td>
<td>≤ 0.025V</td>
</tr>
<tr>
<td></td>
<td>V (7343)</td>
<td></td>
<td>10VDC</td>
<td>≤ 0.015 Ω</td>
<td>2886mA</td>
<td>≤ 0.015V</td>
</tr>
<tr>
<td><strong>Liquid Electrolyte</strong> Aluminum Electrolytic</td>
<td>6.3mm x 6.3mm</td>
<td>100uF ±20%</td>
<td>6.3VDC</td>
<td>≤ 0.360 Ω</td>
<td>250mA</td>
<td>≤ 0.360V</td>
</tr>
<tr>
<td></td>
<td>8mm x 10.5mm</td>
<td></td>
<td>35VDC</td>
<td>≤ 0.080 Ω</td>
<td>850mA</td>
<td>&lt;0.080V</td>
</tr>
<tr>
<td></td>
<td>12.5mm x 14mm</td>
<td></td>
<td>50VDC</td>
<td>≤ 0.230 Ω</td>
<td>490mA</td>
<td>≤ 0.230V</td>
</tr>
<tr>
<td></td>
<td>16mm x 17mm</td>
<td></td>
<td>100VDC</td>
<td>≤ 0.170 Ω</td>
<td>793mA</td>
<td>≤ 0.170V</td>
</tr>
<tr>
<td><strong>Std MnO2 Cathode</strong> Tantalum Electrolytic</td>
<td>B (3528)</td>
<td>100uF ±20%</td>
<td>6.3VDC</td>
<td>≤ 1.2 Ω</td>
<td>258mA</td>
<td>&lt;1.2V</td>
</tr>
<tr>
<td></td>
<td>C (6032)</td>
<td></td>
<td>6.3VDC</td>
<td>≤ 0.90 Ω</td>
<td>350mA</td>
<td>&lt;0.90V</td>
</tr>
<tr>
<td></td>
<td>V (7343)</td>
<td></td>
<td>10VDC</td>
<td>≤ 0.50 Ω</td>
<td>500mA</td>
<td>&lt;0.50V</td>
</tr>
</tbody>
</table>

*Ripple Current Ratings* limited by component Joule heating limitations (also referred to as ohmic heating or resistive heating):

Self-heat temperature ΔT limit of +5°C for aluminum electrolytic capacitors & maximum permissible ΔT of MLCCs generally restricted to +10°C ~ +20°C

www.NICcomp.com | Page 9
### Capacitor Technology Comparison – CV Range

**1uF ~ 2200uF / 2.5VDC ~ 100VDC**

**SMT Capacitor Offering by Technology**

#### Capacitance Voltage Range Comparison

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Capacitance</th>
<th>Icon</th>
<th>Type</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>100VDC</td>
<td>1.0uF</td>
<td>T</td>
<td>Tantalum Electrolytic</td>
<td>SMT Flat Chip</td>
</tr>
<tr>
<td></td>
<td>2.2uF</td>
<td>C</td>
<td>Ceramic Chip - MLCC</td>
<td>SMT Flat Chip</td>
</tr>
<tr>
<td></td>
<td>3.3uF</td>
<td>A</td>
<td>Aluminum Electrolytic</td>
<td>SMT V-Chip</td>
</tr>
<tr>
<td></td>
<td>4.7uF</td>
<td>S</td>
<td>Solid Aluminum Electrolytic</td>
<td>SMT Flat Chip</td>
</tr>
<tr>
<td></td>
<td>10uF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22uF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>33uF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>47uF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100uF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>150uF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>220uF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>330uF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>470uF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000uF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2200uF</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Use NIC QuickBUILDER Tool**

Easily select & compare capacitors

Ripple Voltage & ESR – Aluminum Electrolytic Capacitor Comparison

Comparison in Application:
Ripple Voltage over Temperature
DC-DC Converter

ADVANTAGE: Hybrid Construction *NSPE*
Has stable ESR over Temperature
*Stable Ripple Voltage over Temperature*

<table>
<thead>
<tr>
<th>Room Temperature: +25°C</th>
<th>Cold Temperature: -20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low ESR liquid electrolyte e-cap</strong></td>
<td><strong>Low ESR liquid electrolyte e-cap</strong></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Liquid Technology</strong></td>
<td><strong>Hybrid Technology</strong></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Low ESR = Low Ripple Voltage</strong></td>
<td><strong>Low ESR = Low Ripple Voltage</strong></td>
</tr>
</tbody>
</table>

www.NICcomp.com | Page 11
Ripple Voltage & ESR – Aluminum Electrolytic Capacitor Comparison

Capacitor Type Comparison
ESR over Temperature

Typical 100KHz ESR over Temperature Comparison
100uF @ 35VDC / 8mm Diameter

100KHz ESR: 1.30Ω
@ -55°C

Hybrid Construction NSPE
Much lower ESR & Z over Temperature

100KHz ESR: 0.023Ω @ -55°C

Liquid Electrolyte NACY

Advantage Hybrid Construction

NSPE-H101M35V8x10.8F
NACY101M35V8x10.5F

Liquid Technology

Best

www.NICcomp.com | Page 12
### Capacitor Type Comparison: Liquid & Hybrid Construction

**Low ESR = Low Ripple Voltage**

<table>
<thead>
<tr>
<th>Series / Type</th>
<th>Liquid Technology</th>
<th>Hybrid Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case Size</td>
<td>16mm X 17mm</td>
<td>8mm X 10.8mm</td>
</tr>
<tr>
<td>100KHz ESR</td>
<td>0.060 Ω</td>
<td>0.035 Ω</td>
</tr>
<tr>
<td>100KHz RCR</td>
<td>1610mArms</td>
<td>1670mArms</td>
</tr>
<tr>
<td>Life Rating @ +105°C</td>
<td>2000 hours</td>
<td>10,000 hours</td>
</tr>
<tr>
<td>WVDC</td>
<td>50VDC</td>
<td>50VDC</td>
</tr>
<tr>
<td>Capacitance</td>
<td>1000uF</td>
<td>33uF</td>
</tr>
<tr>
<td>NIC PN</td>
<td>NACY102M50V16X17</td>
<td>NSPE-H330M50V8X10.8</td>
</tr>
<tr>
<td>SMT Format</td>
<td>16mm Diameter</td>
<td>8mm Diameter</td>
</tr>
<tr>
<td></td>
<td>17mm Height</td>
<td>10.8mm Height</td>
</tr>
<tr>
<td>Soldering Heat</td>
<td>+235°C Reflow</td>
<td>+260°C Reflow</td>
</tr>
</tbody>
</table>

**Hybrid Advantages**
- Much Smaller Size & Lower Profile
- Lower ESR
- Higher Current Rating
- Much Longer Life

**Hybrid Technology**
- Higher ESR Rated

---

www.NICcomp.com | Page 13
Capacitor Type Comparison

ESR over Frequency

<table>
<thead>
<tr>
<th>Capacitor Type</th>
<th>ESR @ 100KHz</th>
<th>ESR @ 1MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Electrolytic</td>
<td>0.097Ω</td>
<td>0.085Ω</td>
</tr>
<tr>
<td>Hybrid Construction NSPE-H</td>
<td>0.020Ω</td>
<td>0.014Ω</td>
</tr>
<tr>
<td>Liquid Electrolyte NACY</td>
<td>0.097Ω</td>
<td>0.085Ω</td>
</tr>
</tbody>
</table>

Lowest ESR = Lowest Ripple Voltage

Hybrid Construction NSPE-H offers the best performance with lower ESR and Z over frequency, making it the optimal choice for such applications.
Capacitor Comparison in Application: Liquid & Hybrid Construction In DC-DC Converter

**Application: DC-DC converter**
- Input: 6VDC  Output: 3.5VDC
- Current: 5A  Frequency: 250KHz

**Low ESR Hybrid Capacitors:**
- Reduce component count
- Less PCB space
- Fewer placements

**Hybrid Advantages**
- Reduce Number of Components per PCB

**8** x 330uF/ 10VDC
- P/N: NACZ331M10V
- Low ESR liquid electrolyte e-cap

**3** x 330uF/ 10VDC
- P/N: NSPE331M10V
- Hybrid electrolyte e-cap

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Ripple Voltage & ESR – Hybrid Aluminum Electrolytic Capacitors

Application:
DC-DC Converter for POE

48VDC application using LTC1871-1
PoE application ... High capacitance value with ESR less than 0.1 Ohm, current rating of >1.5A, and voltage rating of 63VDC (or higher)

LTC1871-1 DESCRIPTION
Wide Input Range, Boost, Flyback and SEPIC Controller.
.. Please note that the input capacitor can see a very high surge current when a battery is suddenly connected to the input of the converter and solid tantalum capacitors can fail catastrophically under these conditions. Be sure to specify surge-resistant capacitors!

Suggested Part Number:
NSPE-H330M63V10X10.8NBF
- 10,000 Hours @ 105°C
- 33uF @ 63VDC
- Low ESR = 0.030 Ω
- Ripple Current = 2100mA
- 10 x 10.8mm SMT Size

Hybrid Advantage:
- Ability to handle surge transient events
- Excellent inrush current characteristics
- Low ESR at High VDC

Lowest ESR = Lowest Ripple Voltage

www.NICcomp.com | Page 16
Ripple Voltage & ESR – Hybrid Aluminum Electrolytic Capacitors

**Application:**
DC-DC Converter - Fan Driver

**Target Driver Chip**
**Nat Semi - LM5116**
Synchronous Buck Controller
Wide output from 1.2V to **80V**

**PN: NSPE-H151M35V10X10.8NBYF**
- Operating Temperature -55°C ~ 105°C
- Capacitance **150uF ± 20%** / Voltage **35VDC**
- ESR **23mΩ** (+20°C/100KHz)
- Ripple Current Rating **2470mA** (100KHz/+105°C)
- Load Life **10,000Hrs @ +105°C**
- Dimensions: D = 10mm x L max. = 10.8mm

Lowest ESR = Lowest Ripple Voltage
## Ripple Voltage & ESR – Hybrid Aluminum Electrolytic Capacitors

### NSPE Series – Polymer Hybrid Aluminum Electrolytic Capacitors

<table>
<thead>
<tr>
<th>Series</th>
<th>Temp Range</th>
<th>Life Rate @ Max Temp</th>
<th>Voltage Rating</th>
<th>Cap Range</th>
<th>100KHz ESR</th>
<th>100Hz RCR @ Max Temp</th>
<th>Reflow Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSPE-S</td>
<td>-55°C +105°C</td>
<td>3K &amp; 5Khrs</td>
<td>6.3 ~ 16VDC</td>
<td>10 ~ 1000uF</td>
<td>≥0.015Ω</td>
<td>≤3.89A</td>
<td>+250°C</td>
</tr>
<tr>
<td>NSPE-H</td>
<td>-55°C +105°C</td>
<td>5K ~ 10Khrs</td>
<td>25 ~ 125VDC</td>
<td>2.7 ~ 270uF</td>
<td>≥0.022Ω</td>
<td>≤2.53A</td>
<td>+260°C</td>
</tr>
<tr>
<td>NSPE-T</td>
<td>-55°C +125°C</td>
<td>1.5 ~ 3Khrs</td>
<td>25 ~ 125VDC</td>
<td>3.9 ~ 270uF</td>
<td>≥0.022Ω</td>
<td>≤1.52A</td>
<td>+260°C</td>
</tr>
<tr>
<td>NSPE-U</td>
<td>-55°C +125°C</td>
<td>2Khrs</td>
<td>6.3 ~ 16VDC</td>
<td>22 ~ 560uF</td>
<td>≥0.016Ω</td>
<td>≤2.19A</td>
<td>+250°C</td>
</tr>
<tr>
<td>NSPE-Y</td>
<td>-55°C +135°C</td>
<td>2Khrs</td>
<td>25 ~ 63VDC</td>
<td>22 ~ 270uF</td>
<td>≥0.022Ω</td>
<td>≤1.22A</td>
<td>+260°C</td>
</tr>
</tbody>
</table>

**Lowest ESR = Lowest Ripple Voltage**

### Case Sizes: (D x H) mm

- 6.3 x 4.8
- 6.3 x 6.3
- 6.3 x 8
- 8 x 10.8
- 10 x 10.8
- 10 x 12.8
Hybrid Aluminum Electrolytic Capacitors – Road Map

NSPE Series – Polymer Hybrid Aluminum Electrolytic Capacitors

Current NSPE Specifications:
- NSPE-H  +105°C 25V ~ 100VDC
- NSPE-T  +125°C 25V ~ 100VDC
- NSPE-Y  +135°C 25V ~ 63VDC

2011

125V (10uF, 10x10.5)
Higher Voltage
NSPE-H & NSPE-T

New Sizes
6.3x4.8 Low Profile
10x12.5 High Cap - Volt
NSPE-H, NSPE-T & NSPE-Y

2012

Higher Voltage
160VDC
10 x 10.5 size

Next Size
8x9.5 & 10x9.5
Low Profile

Higher Temp Rating
+150°C
8x12.8 & 10 x 14.8 sizes

www.NICcomp.com | Page 19
Summary:

Industry trends require output circuit capacitors, with low ESR, to meet reduced supply bias noise requirements (reduced ripple voltage).

Minimizing the ESR in the output capacitors is a continuing goal.

Lowest ESR capacitors types include:

- MLCC Ceramic
- Solid Polymer Aluminum Electrolytic
- Hybrid (Liquid & Solid Polymer) Construction Aluminum Electrolytic
- Polymer Cathode Tantalum Electrolytic

For Higher VDC circuit applications, Hybrid (Liquid & Solid Polymer) Construction Aluminum Electrolytic Capacitors have advantage of low ESR, stability over temperature, space savings and working voltage ratings up to 125VDC.
Additional Information Needed?
Need Samples?

Technical Support: tpmg@niccompcom
Sales Support: sales@niccomp.com

NIC Components offers unique performance passive components that provide advantages to design engineers to create high performance end products in smaller and lower total cost formats

• Surface Mount SMT formats (high speed auto placement)
• Pb-Free Reflow Compatible (high temperature reflow)
• Performance advantages over competing technologies