Parkesburg Pennsylvania – a very special place where 21st Century technology converges with Old World ethics.

High Energy Corporation is housed in a modern factory at the edge of time. Historic Parkesburg stands at the eastern gateway to Pennsylvania’s Lancaster County, a place where time sometimes seems to stand still. Our neighbors farm in centuries-old fashion. Come to visit us and your car may share the road with an Amish buggy or a horse-drawn farm wagon. Our people reflect the values of their surroundings; they are hard working, honest to a fault and loyal to their employer and to their customers. Parkesburg residents have been this way for over 200 years and will not change. While our technology advances at the pace of modern-world commerce, our values remain true to an older time and stricter code. We may be an anachronism, but we like it this way. Our customers have come to appreciate doing business in an old fashioned manner within the modern world.

Partner with us and enjoy the benefits of buying first-rate modern technology components from people who exalt old-world craftsmanship and view their word as a bond. Step back in time and forward in technology by choosing High Energy Corporation capacitors for your products.

http://www.highenergycorp.com

Sales@HighEnergyCorp.com (610) 593-2800 FAX (610) 593-2985
Custom Metallized Film Capacitors and Special Designs 2

We will design and fabricate exactly what you need.

Standard Conduction-Cooled Metallized Film Capacitors

Series CHD - 0.1 to 0.2 μF, 700 V_{RMS}, 250 A_{RMS}, 150 kVA, 700 kHz
Series CHE - 0.2 to 2.0 μF, 525 to 700 V_{RMS}, 550 to 800 A_{RMS}, 325 to 400 kVA, 700 kHz
Series CHF - 0.1 to 1.32 μF, 600 to 1000 V_{RMS}, 400 to 650 A_{RMS}, 300 kVA, 1000 kHz
Series CHG - 0.11 to 2.4 μF, 400 to 700 V_{RMS}, 180 to 500 A_{RMS}, 125 to 325 kVA, 500 kHz
Series CHH - 0.1 to 2.5 μF, 400 to 700 V_{RMS}, 250 to 400 A_{RMS}, 160 kVA, 800 to 1000 kHz
Series CHJ - 0.18 to 5.0 μF, 300 to 700 V_{RMS}, 375 to 600 A_{RMS}, 180 to 210 kVA, 300 to 600 kHz
Series CHL - 0.1 to 2.5 μF, 400 to 700 V_{RMS}, 250 to 400 A_{RMS}, 160 kVA, 800 to 1000 kHz
Series CHM - 0.1 to 2.5 μF, 400 to 700 V_{RMS}, 250 to 400 A_{RMS}, 160 kVA, 800 to 1000 kHz

Series CHN0 - 1.4 to 10 μF, 600 to 650 V_{RMS}, 400 to 600 A_{RMS}, 250 kVA, 70 kHz
Series CHN6 - 0.03 to 1.2 μF, 450 to 1000 V_{RMS}, 125 to 275 A_{RMS}, 120 kVA, 1000 kHz

Standard Water-Cooled Metallized Film Capacitors

Series CHX 0.06 μF, 1500 to 700 V_{RMS}, 200 A_{RMS}, 3000 kVA, 800 to 450 kHz

Metallized Film Background & Theory

Warranty Statement

High Energy Corporation metallized film capacitors in conformity to RoHS Directive are optionally available upon request. Specifically, in conformity with EU Directive 2002/95/EC, lead, cadmium, mercury, hexavalent chromium and specific bromine-based flame-retardants, PBB and PBDE, will not be used.

Note: Product specifications are subject to change without notice.

http://www.highenergycorp.com

HIGH ENERGY CORP.

P.O. Box 308 Lower Valley Road Parkesburg, PA 19365
In today’s ‘modern’ business climate, companies tend to provide products that fit the general needs of the industry they serve and to avoid deviating from these popular offerings. However, such ‘blister-pack’ solutions don’t always serve the customer well. **High Energy Corporation** takes a different stance; we welcome the challenge of providing custom parts of the highest quality, rapidly and at a fair price.

We are an Engineering managed and driven enterprise and we welcome the chance to partner with our customers and to bring our unique capabilities to bear upon the development, refinement and evolution of state-of-the-art metallized film capacitors. Whether your needs are for a simple custom value in one of our standard products, or for an entirely new packaging concept, we are ready to work with you in refining your high voltage, current, power or frequency application.
This catalog illustrates many standard High Energy Corporation products. Think of these as a launch point for your product planning and design thoughts. We will be delighted to produce exactly the ‘right’ component for your new design or for your mature product and you will be delighted with the result! Peruse some unique custom parts designed for others here.
• 700 $V_{\text{RMS}}$ Working Voltage  
• 150 kVA Max Power  
• 250 $A_{\text{RMS}}$ Max Current  
• Conduction Cooled  
• Series & Parallel Stackable

**GENERAL SPECIFICATIONS**

**Capacitance Range** 0.1 to 0.2 $\mu$F standard; 0.01 to 0.33 custom

**Capacitance Tolerance** ± 10% standard, other tolerances available

**Dimensions** 68 x 33 x 22.5 mm
2 $^{1/16}$ x 1 $^{5/32}$ x $^{7/8}$ inch

**Weight** 0.2 kg; .44 lb

**Operating Temperature** Up to +90° C

**Cooling method** Conduction-cooled by bus bars

**Dissipation Factor** 0.1% Maximum

**Stray Inductance** less than 5 nH

<table>
<thead>
<tr>
<th>CAP ($\mu$F)</th>
<th>$V_{\text{MAX}}$ ($V_{\text{RMS}}$)</th>
<th>$f_L$ (kHz)</th>
<th>$S_{\text{MAX}}$ (kVA)</th>
<th>$f_H$ (kHz)</th>
<th>$I_{\text{MAX}}$ ($A_{\text{RMS}}$)</th>
<th>$f_{\text{MAX}}$ (kHz)</th>
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Custom capacitance values are available upon request.
Typical Maximum Rating Curves for CHD Series Capacitors
GENERAL SPECIFICATIONS

Capacitance Range 0.2 to 2.0 μF standard; 0.01 to 0.33 custom
Capacitance Tolerance ± 10% standard, other tolerances available
Dimensions 70 x 57 x 41 mm
2 3/4 x 2 1/4 x 2 5/8 inch
Weight 0.5 kg; 1.1 lb
Operating Temperature Up to +90° C
Cooling method Conduction-cooled by bus bars
Dissipation Factor 0.1% Maximum
Stray Inductance less than 5 nH

<table>
<thead>
<tr>
<th>CAP (μF)</th>
<th>VMAX (VRMS)</th>
<th>fL (kHz)</th>
<th>SMAX (kVA)</th>
<th>fH (kHz)</th>
<th>IMAX (ARMS)</th>
<th>fMAX (kHz)</th>
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<td>740</td>
<td>550</td>
<td>700</td>
<td>CHE6020M</td>
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<tr>
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<td>320</td>
<td>325</td>
<td>448</td>
<td>550</td>
<td>700</td>
<td>CHE6033M</td>
</tr>
<tr>
<td>0.66</td>
<td>700</td>
<td>160</td>
<td>325</td>
<td>224</td>
<td>550</td>
<td>700</td>
<td>CHE6066M</td>
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<tr>
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<td>400</td>
<td>224</td>
<td>750</td>
<td>700</td>
<td>CHE6100M</td>
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<tr>
<td>1.5</td>
<td>525</td>
<td>154</td>
<td>400</td>
<td>170</td>
<td>800</td>
<td>700</td>
<td>CHE6150M</td>
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<tr>
<td>2.0</td>
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<td>700</td>
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Custom capacitance values are available upon request.
Typical Maximum Rating Curves for CHE Series Capacitors

**CHE6020M**
- 0.2 µF
- Ambient Temperature = 25 °C

**CHE6033M**
- 0.33 µF
- Ambient Temperature = 25 °C

**CHE6066M**
- 0.66 µF
- Ambient Temperature = 25 °C

**CHE6100M**
- 1 µF
- Ambient Temperature = 25 °C

**CHE6150M**
- 1.5 µF
- Ambient Temperature = 25 °C

**CHE6200M**
- 2 µF
- Ambient Temperature = 25 °C

- 700 kVAR
- 550 Amps
- 325 kVA

- 700 kVAR
- 550 Amps
- 325 kVA

- 600 kVAR
- 750 Amps
- 400 kVA

- 525 kVAR
- 600 Amps
- 490 kVA

- 525 kVAR
- 600 Amps
- 490 kVA
GENERAL SPECIFICATIONS

- Capacitance Range: 0.18 to 1.2 μF standard; 0.01 to 0.33 custom
- Capacitance Tolerance: ± 10% standard, other tolerances available
- Dimensions: 49 x 49 x 30 mm
  - 1 15/16 x 1 15/16 x 1 3/16 inch
- Weight: 0.25 kg; 0.5 lb
- Operating Temperature: Up to +90° C
- Cooling method: Conduction-cooled by bus bars
- Dissipation Factor: 0.1% Maximum
- Stray Inductance: less than 5 nH

<table>
<thead>
<tr>
<th>CAP (μF)</th>
<th>VMAX (V RMS)</th>
<th>fL (kHz)</th>
<th>SMAX (kVA)</th>
<th>fH (kHz)</th>
<th>IMAX (ARMS)</th>
<th>fMAX (kHz)</th>
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<td>300</td>
<td>401</td>
<td>500</td>
<td>500</td>
<td>CHF6033M</td>
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<td>CHF6100M</td>
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<td>100</td>
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<td>170</td>
<td>650</td>
<td>300</td>
<td>CHF6132M</td>
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Custom capacitance values are available upon request.
Up to 700 $V_{RMS}$ Working Voltage
Up to 375 kVA Max Power
Up to 625 $A_{RMS}$ Max Current
Conduction Cooled
Series & Parallel Stackable

**GENERAL SPECIFICATIONS**

<table>
<thead>
<tr>
<th>Capacitance Range</th>
<th>0.11 to 2.4 μF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance Tolerance</td>
<td>± 10% standard, other tolerances available</td>
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<tr>
<td>Dimensions</td>
<td>CHG5 – 76.2 x 37.8 x 39.2 (mm) 3 x 1 $1\frac{1}{16}$ x 1 $3\frac{3}{4}$ (inch) CHG6 – 76.2 x 50.8 x 39.2 3 x 2 x 1 $3\frac{3}{4}$</td>
</tr>
<tr>
<td>Weight</td>
<td>CHG5 – 0.14 (kg) CHG6 – 0.23 0.30 (lb) 0.50</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>Up to +90° C</td>
</tr>
<tr>
<td>Cooling method</td>
<td>Conduction-cooled by bus bars</td>
</tr>
<tr>
<td>Dissipation Factor</td>
<td>0.1% Maximum</td>
</tr>
<tr>
<td>Stray Inductance</td>
<td>less than 5 nH</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CAP $(\mu F)$</th>
<th>$V_{MAX}$ $(V_{RMS})$</th>
<th>$f_L$ (kHz)</th>
<th>$S_{MAX}$ (kVA)</th>
<th>$f_H$ (kHz)</th>
<th>$I_{MAX}$ $(A_{RMS})$</th>
<th>$f_{MAX}$ (kHz)</th>
<th>Value Available</th>
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<td>300</td>
<td>500</td>
<td>√</td>
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<td>500</td>
<td>√</td>
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Add suffix E for (as in CHG5018ME) for epoxy-potted part.
Custom capacitance values are available upon request.
Typical Maximum Rating Curves for CHG Series Capacitors

CHG5018 & CHG6018

0.18 µF

Ambient Temperature = 25 °C

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<th>Frequency (MHz)</th>
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<th>Current</th>
<th>Power</th>
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<tr>
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CHG5021 & CHG6021

0.21 µF

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CHG5033 & CHG6033

0.33 µF

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</tr>
<tr>
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CHG5051 & CHG6051

0.54 µF

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<th>Power</th>
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CHG5066 & CHG6066

0.86 µF

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<tr>
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<tr>
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CHG6120

1.2 µF

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</tr>
<tr>
<td>1000</td>
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CHG6240

2.4 µF

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<th>Voltage</th>
<th>Current</th>
<th>Power</th>
</tr>
</thead>
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<td></td>
</tr>
<tr>
<td>1000</td>
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</table>

Ambient Temperature = 25 °C

Voltage
Current
Power
GENERAL SPECIFICATIONS

Capacitance Range  
0.1 to 2.5 µF standard; 0.01 to 0.33 custom

Capacitance Tolerance  
± 10% standard, other tolerances available

Dimensions  
68 x 30.2 x 30.2 mm  
2 11/16 x 1 3/16 x 1 3/16 inch

Weight  
0.5 kg; 1.1 lb

Operating Temperature  
Up to +90° C

Cooling method  
Conduction-cooled by bus bars

Dissipation Factor  
0.1% Maximum

Stray Inductance  
less than 5 nH

<table>
<thead>
<tr>
<th>CAP (µF)</th>
<th>V_{MAX} (V_{RMS})</th>
<th>f_L (kHz)</th>
<th>S_{MAX} (kVA)</th>
<th>f_H (kHz)</th>
<th>I_{MAX} (A_{RMS})</th>
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Custom capacitance values are available upon request.
GENERAL SPECIFICATIONS

Capacitance Range  
0.18 to 5.0 µF standard; 0.01 to 0.33 custom

Capacitance Tolerance  
± 10% standard, other tolerances available

Dimensions  
76.2 x 50.8 x 36.5 mm
3 x 2 x 1 7/16 inch

Weight  
0.27 kg; 0.6 lb

Operating Temperature  
Up to +90°C

Cooling method  
Conduction-cooled by bus bars

Dissipation Factor  
0.1% Maximum

Stray Inductance  
less than 5 nH

<table>
<thead>
<tr>
<th>CAP (µF)</th>
<th>V&lt;sub&gt;MAX&lt;/sub&gt; (V&lt;sub&gt;RMS&lt;/sub&gt;)</th>
<th>f&lt;sub&gt;L&lt;/sub&gt; (kHz)</th>
<th>S&lt;sub&gt;MAX&lt;/sub&gt; (kVA)</th>
<th>f&lt;sub&gt;H&lt;/sub&gt; (kHz)</th>
<th>I&lt;sub&gt;MAX&lt;/sub&gt; (A&lt;sub&gt;RMS&lt;/sub&gt;)</th>
<th>f&lt;sub&gt;MAX&lt;/sub&gt; (kHz)</th>
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</thead>
<tbody>
<tr>
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Custom capacitance values are available upon request.
Typical Maximum Rating Curves for CHJ Series Capacitors

CHJ6018M
8.18 μF
700 V max
375 A max
218 V A
Ambient Temperature = 25 °C

CHJ6024M
8.24 μF
700 V max
375 A max
218 V A
Ambient Temperature = 25 °C

CHJ6033M
8.33 μF
700 V max
375 A max
218 V A
Ambient Temperature = 25 °C

CHJ6066M
8.66 μF
650 V max
475 A max
218 V A
Ambient Temperature = 25 °C

CHJ6120M
8.7 μF
505 V max
505 A max
218 V A
Ambient Temperature = 25 °C

CHJ6240M
2.4 μF
400 V max
400 A max
218 V A
Ambient Temperature = 25 °C

CHJ6566M
5 μF
300 V max
666 A max
98 V A
Ambient Temperature = 25 °C
• Up to 700 $V_{RMS}$ Working Voltage
• 160 kVA Max Power
• Up to 400 $A_{RMS}$ Max Current
• Conduction Cooled
• Series & Parallel Stackable

GENERAL SPECIFICATIONS

Capacitance Range 0.1 to 2.5 μF standard; 0.01 to 0.33 custom
Capacitance Tolerance ± 10% standard, other tolerances available
Dimensions 68 x 32 x 30.2 mm
2$^{1/16}$ x 1$^{1/4}$ x 1$^{3/16}$ inch
Weight 0.5 kg; 1.1 lb
Operating Temperature Up to +90° C
Cooling method Conduction-cooled by bus bars
Dissipation Factor 0.1% Maximum
Stray Inductance less than 5 nH

<table>
<thead>
<tr>
<th>CAP (μF)</th>
<th>$V_{MAX}$ (V RMS)</th>
<th>$f_L$ (kHz)</th>
<th>$S_{MAX}$ (kVA)</th>
<th>$f_H$ (kHz)</th>
<th>$I_{MAX}$ (A RMS)</th>
<th>$f_{MAX}$ (kHz)</th>
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Custom capacitance values are available upon request.
Typical Maximum Rating Curves for CHL Series Capacitors
**GENERAL SPECIFICATIONS**

- **Capacitance Range**: 0.1 to 2.5 \( \mu \text{F} \) standard; 0.01 to 0.33 custom
- **Capacitance Tolerance**: ± 10% standard, other tolerances available
- **Dimensions**: 70 x 32 x 30.2 mm
  \[ 2\frac{3}{4} \times 1\frac{1}{4} \times 1\frac{3}{16} \text{ inch} \]
- **Weight**: 0.5 kg; 1.1 lb
- **Operating Temperature**: Up to +90° C
- **Cooling method**: Conduction-cooled by bus bars
- **Dissipation Factor**: 0.1% Maximum
- **Stray Inductance**: less than 5 nH

### CAP

<table>
<thead>
<tr>
<th>( \mu \text{F} )</th>
<th>( V_{\text{MAX}} )</th>
<th>( f_L )</th>
<th>( S_{\text{MAX}} )</th>
<th>( f_H )</th>
<th>( I_{\text{MAX}} )</th>
<th>( f_{\text{MAX}} )</th>
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<td>CHM6017M</td>
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<td>800</td>
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CUSTOM capacitance values are available upon request.
Typical Maximum Rating Curves for CHM Series Capacitors

- **CHM6010M**
  - 0.1 µF
  - Ambient Temperature = 25 °C
  - 790 kVAR
  - 250 Amperes
  - 160 kVA

- **CHM6017M**
  - 0.17 µF
  - Ambient Temperature = 25 °C
  - 790 kVAR
  - 250 Amperes
  - 160 kVA

- **CHM6033M**
  - 0.33 µF
  - Ambient Temperature = 25 °C
  - 790 kVAR
  - 275 Amperes
  - 160 kVA

- **CHM6066M**
  - 0.66 µF
  - Ambient Temperature = 25 °C
  - 790 kVAR
  - 300 Amperes
  - 160 kVA

- **CHM6120M**
  - 1.2 µF
  - Ambient Temperature = 25 °C
  - 590 kVAR
  - 325 Amperes
  - 160 kVA

- **CHM6250M**
  - 2.5 µF
  - Ambient Temperature = 25 °C
  - 490 kVAR
  - 400 Amperes
  - 160 kVA

*Graphs showing frequency response for different capacitor values and ratings.*
GENERAL SPECIFICATIONS

Capacitance Range 1.4 to 10 μF
Capacitance Tolerance ± 10% standard, other tolerances available
Dimensions 80 mm (maximum) diameter x 70 mm high
3 1/8 (maximum) diameter x 2 3/4 high
Weight .75 kg; 1.7 lb
Operating Temperature Up to +90° C
Cooling method Conduction-cooled by bus bars
Dissipation Factor 0.1% Maximum
Stray Inductance less than 5 nH

<table>
<thead>
<tr>
<th>CAP (μF)</th>
<th>VMAX (VRMS)</th>
<th>fL (kHz)</th>
<th>SMAX (kVA)</th>
<th>fH (kHz)</th>
<th>IMAX (ARMS)</th>
<th>fMAX (kHz)</th>
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Custom capacitance values are available upon request.
Typical Maximum Rating Curves for CHN0 Series Capacitors

- **CHN0140M250**: 1.4 μF, Ambient Temperature = 25 °C
- **CHN0220M250**: 2.2 μF, Ambient Temperature = 25 °C
- **CHN0300M250**: 3 μF, Ambient Temperature = 25 °C
- **CHN0620M250**: 6.2 μF, Ambient Temperature = 25 °C
- **CHN0850M250**: 8.5 μF, Ambient Temperature = 25 °C
- **CHN1000M250**: 10 μF, Ambient Temperature = 25 °C

Frequency (kHz) vs. Voltage, Current, Power.
• Up to 1000 \( V_{RMS} \) Working Voltage
• 120 kVA Max Power
• Up to 125 \( A_{RMS} \) Max Current
• Conduction Cooled

**GENERAL SPECIFICATIONS**

<table>
<thead>
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<th>Capacitance Range</th>
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<td>Dimensions</td>
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<tr>
<td>Weight</td>
<td>( .15 ) kg; ( .33 ) lb</td>
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<tr>
<td>Operating Temperature</td>
<td>Up to ( +90^\circ ) C</td>
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<tr>
<td>Cooling method</td>
<td>Conduction-cooled by bus bars</td>
</tr>
<tr>
<td>Dissipation Factor</td>
<td>0.1% Maximum</td>
</tr>
<tr>
<td>Stray Inductance</td>
<td>less than 5 nH</td>
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<table>
<thead>
<tr>
<th>CAP (( \mu F ))</th>
<th>( V_{MAX} ) (( V_{RMS} ))</th>
<th>( f_L ) (kHz)</th>
<th>( S_{MAX} ) (kVA)</th>
<th>( f_H ) (kHz)</th>
<th>( I_{MAX} ) (( A_{RMS} ))</th>
<th>( f_{MAX} ) (kHz)</th>
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<td>83</td>
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<td>1000</td>
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Custom capacitance values are available upon request.
Typical Maximum Rating Curves for CHN6 Series Capacitors

- **CHN6003M**: 8.05 µF, Ambient Temperature = 25 °C
  - Maximum Voltage: 525 V
  - Maximum Current: 12 mA
- **CHN6009M**: 8.09 µF, Ambient Temperature = 25 °C
  - Maximum Voltage: 450 V
  - Maximum Current: 12 mA
- **CHN6009M**: 8.99 µF, Ambient Temperature = 25 °C
  - Maximum Voltage: 450 V
  - Maximum Current: 12 mA
- **CHN6017M**: 8.17 µF, Ambient Temperature = 25 °C
  - Maximum Voltage: 575 V
  - Maximum Current: 12 mA
- **CHN6025M**: 8.25 µF, Ambient Temperature = 25 °C
  - Maximum Voltage: 575 V
  - Maximum Current: 12 mA
- **CHN6033M**: 8.33 µF, Ambient Temperature = 25 °C
  - Maximum Voltage: 610 V
  - Maximum Current: 12 mA
- **CHN6066M**: 8.66 µF, Ambient Temperature = 25 °C
  - Maximum Voltage: 610 V
  - Maximum Current: 12 mA
- **CHN6120M**: 1.2 µF, Ambient Temperature = 25 °C
  - Maximum Voltage: 450 V
  - Maximum Current: 12 mA
GENERAL SPECIFICATIONS

Capacitance Range  
0.06 μF standard; up to 0.069 μF custom

Capacitance Tolerance  
± 10% standard, other tolerances available

Dimensions  
53 mm diameter x 71 mm high  
2 1/16” diameter x 2 13/16” high

Weight  
.36 kg; .79 lb

Operating Temperature  
Up to +90° C

Cooling method  
Individually water-cooled

Dissipation Factor  
0.1% Maximum

Stray Inductance  
less than 5 nH

<table>
<thead>
<tr>
<th>CAP (μF)</th>
<th>V_MAX (V_RMS)</th>
<th>f_L (kHz)</th>
<th>S_MAX (kVA)</th>
<th>f_H (kHz)</th>
<th>I_MAX (A_RMS)</th>
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* Electrical parameters of custom parts vary with the specified capacitance value.
COOLING REQUIREMENTS

Capacitor Temperature  Not to exceed 90° C
Temperature Rise       The capacitor can exhibit a temperature rise of up to 40° C at full rated power
Water Temperature      Inlet water temperature must be 50° C or less
Flow Rate              1.5 liter/minute (0.41 gpm) or more
Cooling Water Pressure Not to exceed 4 Bar (60 PSIG)
The anatomy of a generic metallized film capacitor.

A metallized film capacitor is composed of a wound core soldered between copper terminals. The wound core is a seemingly simple thing, but it is really quite a sophisticated component. In the simplest embodiment, it consists of two metallic electrodes separated by an insulating dielectric, a thin film of polypropylene.

Two long and narrow ‘plates’ separated by a thin dielectric are formed. The resulting capacitance is determined by the *surface area* of the electrodes, $A$, the *thickness*, $t$, of the separating dielectric and the *relative dielectric constant*, $K$, of the separating film. In specific:

$$C = \frac{KA\varepsilon_0}{t}$$

$C$ = Capacitance in Farads (F)  
$K$ = Relative Dielectric Constant (dimensionless)  
$A$ = Surface area of each electrode ($m^2$)  
$\varepsilon_0$ = Permittivity of vacuum = $8.854 \times 10^{-12} \text{ F/m}$  
$t$ = Thickness of dielectric between electrodes (m)

High Energy Corporation employs many different types of core windings in its broad line of metallized film capacitors. Each is chosen to optimize the component for a specific mission profile.

Metallized film capacitors offer high capacitance in a small package. They can pass nearly awesome reactive currents without failure and they withstand very significant voltage potentials without damage. These rugged and reliable (self-healing) high power capacitors call upon a complex interlocking myriad of manufacturing processes to make them a reality.

**Basic Electronic Considerations**

The *impedance* of an ideal capacitor is the complex spectrum given by:

$$Z(f) = \frac{V(f)}{i(f)} = \frac{I}{2\pi fC} e^{-90^\circ}$$

$Z$ = Impedance in Ohms (Ω)  
$f$ = Frequency in Hertz (Hz)  
$C$ = Capacitance in Farads (F)  
$V$ = Electromotive Force (Volt)  
$I$ = Current (Ampere)  
$\pi = 3.14159 ...$

However, as illustrated below, a real capacitor will have imperfections that can be modeled by series and parallel resistors and a series inductor. A more complicated impedance results.

**Equivalent circuit model for a metallized film capacitor.**

- Effect of (exaggerated) $R_p$ and $R_s$ on impedance.

---

Effect of $R_p = 100 \text{ Ohm}$

Effect of $R_p = 1 \text{ Ohm}$

Ideal 1 μF Capacitor ($Z = \frac{1}{2\pi fC}$)

Effect of $R_p = 100 \text{ Ohm}$

Effect of $R_p = 1 \text{ Ohm}$

Ideal 1 μF Capacitor
As shown (by the red traces) in the directly preceding figure, the magnitude of a \(1 \mu F\) capacitor’s impedance decreases in proportion to frequency while its phase angle is a constant -90°. The black traces illustrate the (exaggerated) effects of parallel and series resistors, \(R_p\) and \(R_s\).

A low value of parallel or ‘leakage’ resistor, \(R_p\), causes a reduction of the capacitor’s impedance at frequencies less than \(1/2\pi R_p C\) Hz. It also causes the phase to deviate from -90° towards 0°. A high value of series resistor, \(R_s\), causes an increase in capacitor impedance for frequencies above \(1/2\pi R_s C\) with a phase shift towards 0°.

However, the resistor values (\(R_p = 100 \Omega\) and \(R_s = 1 \Omega\)) of the previous figures are unrealistic. More typical values might be \(R_p = 10 M\Omega\) and \(R_s = 1 m\Omega\) \((10^{-3} \Omega)\), shown in black below. These are compared with the (blue trace) previous exaggerations in Dissipation Factor spectra.

The Dissipation Factor (DF), \(\delta\), is a real-valued spectrum corresponding to the tangent of the impedance phase. As such, it is the ratio of real or phase-coincident response to the imaginary or quadrature-phase response.

The Dissipation Factor is thus also equal to the ratio of (heat producing) real power dissipated within the capacitor to the reactive power oscillating through it. Note that for an ‘ideal’ capacitor (prior red traces) the Dissipation Factor is zero-valued at all frequencies and cannot be plotted in the above log-log format.

Now consider the influence of a “series inductance”, \(L_s\):

The following violet trace shows that the addition of a small series inductance (5 nanoHenry in this case) creates a peak in the Dissipation Factor at the self-resonance frequency, \(f_n\), defined by:

\[
f_n = \frac{1}{2\pi} \sqrt{\frac{1}{LC}} \text{(Hz)}
\]

Note changed frequency axis to accentuate the effects of \(L_s\).

The addition of this component to the capacitor model produces a noticeable ‘notch’ in the impedance magnitude at the same frequency. The most pronounced effect is a 180° ‘jump’ in the impedance phase spectrum at \(f_n\), as shown below.
Performance Limits & Thermodynamics
The Leakage Resistance, $R_L$, is fundamentally determined by the resistivity of the dielectric and the terminal-to-terminal insulation of the capacitor. The Equivalent Series Resistance (ESR), $R_s$, is dominated by the quality of the soldered joints between the terminals and the electrodes. The Equivalent Series Inductance (ESL), $L_s$, is basically determined by the length of the terminal assemblies.

Other considerations limit the performance of a capacitor. The maximum voltage is fundamentally determined by the thickness of the dielectric film, $t$, between the electrodes and the resistivity and the break-down potential of the dielectric. The maximum current is limited by the surface area of the electrodes, $A$ and the thickness of the deposited aluminum electrodes.

Electrical parameters are further limited by thermodynamic considerations. An alternating current passing through a theoretically perfect capacitor generates no heat, as the voltage across the capacitor is 90° out-of-phase with the current. Multiplying (and averaging) the instantaneous voltage and this reactive current produces only imaginary reactive power, $Q$.

In a real capacitor, the voltage, $V$, and current, $I$, are not in perfect phase-quadrature. The total current contains a small (~60 dB, typical) active component, $I_A$, in phase-coincidence with the voltage. The product (of RMS values), $V \cdot I_A$, defines the active electrical power (Watts) dissipated within the capacitor as heat. $I_A$ is well approximated by $I \cdot \delta$, where $\delta$ is the previously defined dissipation factor.

The product of RMS values, $V \cdot I = S$, is always a larger number, termed the apparent power. $S$ reflects both the active and reactive power components in accordance with:

$$S = \sqrt{P^2 + Q^2} \quad \text{(VA)} \quad (4)$$

When the capacitor is at the same temperature ($T_{\text{Ambient}}$) as it surroundings, it cannot expel any heat. As its temperature increases (by $T_{\text{Rise}}$) above the surrounding $T_{\text{Ambient}}$, it is able to pass thermal power, $P_{\text{Heat Out}}$, to the environment.

The amount of heat expelled, $P_{\text{Heat Out}}$, is a function of $T_{\text{Rise}}$. (This relationship is well modeled by a fourth-order polynomial.) When $P_{\text{Heat Out}} = P_{\text{Elect}}$, the capacitor’s temperature stabilizes at $T_{\text{Rise}}$ above $T_{\text{Ambient}}$.

Thus, the capacitor has three very fundamental limiting specifications. These are:

1. Maximum rated operating Voltage, $V_{\text{Max}}$
2. Maximum rated operating Current, $I_{\text{Max}}$
3. Maximum rated operating Apparent Power, $S_{\text{Max}}$

The following figure illustrates typical Maximum Rated power parameters as a function of frequency.

Within that frequency band bounded by lower frequency, $f_L$, and upper frequency, $f_U$, the limiting specification is the maximum rated apparent power. $S_{\text{Max}}$ is that experimentally-determined total power that will cause the capacitor’s temperature to rise 40° C (104° F) above the ambient. Within this full-power frequency band, both the voltage and current must be less than their respective maximum ratings.

Below $f_L$, the limiting specification is the maximum rated voltage, $V_{\text{Max}}$. In this region, both the current and power must be less than their maximum rated values. Above $f_U$, the limiting specification is the maximum rated current, $I_{\text{Max}}$. In this frequency span, both the voltage and power must be less than their maximum rated values.
The apparent power, \( S \), at any frequency, \( f \), is related to the root-mean-square current, \( I_{\text{RMS}} \) by:

\[
S = I_{\text{RMS}}^2 \cdot |Z| = \frac{I_{\text{RMS}}^2}{2 \cdot \pi \cdot f \cdot C} \leq S_{\text{Max}}
\]

When the frequency, \( f \), exactly equals the upper bounding frequency, \( f_U \), the current, \( I_{\text{RMS}} \), must equal \( I_{\text{Max}} \) and (5) can be solved for \( f_U \).

\[
f_U = \frac{I_{\text{Max}}^2}{2 \cdot \pi \cdot C \cdot S_{\text{Max}}} \approx 0.159 \cdot I_{\text{Max}}^2
\]

The apparent power, \( S \), may also be expressed in terms of the voltage across the capacitor, \( V_{\text{RMS}} \).

\[
S = \frac{V_{\text{RMS}}^2}{|Z|} = 2 \cdot \pi \cdot f \cdot C \cdot V_{\text{RMS}}^2 \leq S_{\text{Max}}
\]

Equation (7) can be solved for lower bounding frequency, \( f_L \), where the voltage, \( V_{\text{RMS}} \), must equal \( V_{\text{Max}} \).

\[
f_L = \frac{S_{\text{Max}}}{2 \cdot \pi \cdot C \cdot V_{\text{Max}}^2} \approx 0.159 \cdot S_{\text{Max}}
\]

Thus the maximum rated RMS operating voltage may be stated:

\[
V_{\text{RMS}} = V_{\text{Max}}
\]

\[
V_{\text{RMS}} = \sqrt{\frac{S_{\text{Max}}}{2 \cdot \pi \cdot f \cdot C}}
\]

In like manner, the maximum rated RMS operating current is described by:

\[
I_{\text{RMS}} = 2 \cdot \pi \cdot f \cdot C \cdot V_{\text{Max}}
\]

\[
I_{\text{RMS}} = \sqrt{2 \cdot \pi \cdot f \cdot C \cdot S_{\text{Max}}}
\]

\[
I_{\text{RMS}} = I_{\text{Max}}
\]

**Getting the Heat Out**

Most of the standard parts illustrated in this catalog expel their heat through conduction to the bus bars to which they are attached. In turn, the bus bars must be cooled by continuous water flow. The provided water-cooling must be sufficient to assure that the capacitor (or any capacitor within a bank) never exceeds 90° C (194° F). In general, the cooling water must be 50°C (122 °F) or less.

To assure proper cooling, capacitors must be firmly affixed to the bus bars. Capacitor mounting surfaces must be completely in contact with the bus bars; flat mating surfaces are essential. When the cooling flow is shared between capacitors and induction elements (such as heating coils), it is strongly recommended that the capacitors be cooled first, as they place much less thermal load on the cooling system than do the induction coils.

The specific heat, \( c_p \), of water is 1 calorie/gram °C or 4186 J/kg °C. Multiplying this by water’s density, \( \rho \), (1 kg/l) yields a constant with dimensions of energy per volume x temperature. Remembering the Joule (\( J \)) to be a Watt-Second (Ws) allows us to recognize the dimensions of \( \rho c_p \) to be power per volume-flow x temperature. Thus we can write (11).

\[
\frac{P}{F \cdot \Delta T} = \rho c_p = 4186
\]
Where \( P \) = heat power entering water (Watt)
\( F \) = flow rate of water (liter/second)
\( \Delta T \) = temperature rise of the water (°C)

The maximum real power, \( P \), dissipated (as heat) in an operating capacitor is equal to the dissipation factor, \( \delta \), multiplied by the maximum rated apparent power, \( S_{\text{Max}} \). High Energy metallized film capacitors have a maximum \( \delta \) of 0.001. These parts also exhibit a 40°C temperature rise (\( \Delta T \)) when operated at full rated power. Substituting these characteristics in (11) discloses the minimum cooling flow (l/s).

\[
F = \frac{P}{4186 \cdot \Delta T} = \frac{\delta \cdot 1000 \cdot S_{\text{Max}}}{4186 \cdot \Delta T}
\]

\[
= \frac{0.001 \times 1000 \cdot S_{\text{Max}}}{4186 \times 40} = \frac{S_{\text{Max}}}{167440}
\]

Where \( S_{\text{Max}} \) = Full Rated Power (kVA)

For the minimum cooling flow in liter/minute, use:

\[
lpm = \frac{S_{\text{Max}}}{2791}
\]

For the minimum cooling rate in gallon/minute use:

\[
gpm = \frac{S_{\text{Max}}}{10148}
\]

**Plotting Rating Curves for HEC Parts**
All parts listed in this catalog are presented with five power parameters: \( V_{\text{Max}} \), \( f_L \), \( S_{\text{Max}} \), \( f_U \) and \( I_{\text{Max}} \). These are sufficient information to allow construction of the three maximum rating curves without using equations (5), (9) and (10). To do so, start by copying the log-log plot template at the end of this section or by obtaining a suitable sheet of log-log graph paper.

Begin by striking vertical reference lines at the \( f_L \) and \( f_U \) frequency locations as shown above right.

Then, to plot a Maximum Voltage spectrum, draw a horizontal line at the \( V_{\text{Max}} \) level from the graph’s minimum frequency to \( f_L \). Stop at this location, labeled Point 1.

Draw a construction point two decades to the right and one decade below Point 1, as shown below. Draw a line from Point 1 toward this temporary construction point. Stop the line at Point 2, the intersection with \( f_U \).

Adding a segment with a slope equal to \(-1/2\) to the plot.
From **Point 2** construct a temporary point one decade to the right and one decade below **Point 2**, as shown below. Draw a line from **Point 2** through this temporary construction point to the graph’s maximum frequency.

![Graph showing VMax construction](image1)

Completing the $V_{\text{Max}}$ plot with a segment with a $-1$ slope.

To construct a *Maximum Power* diagram, draw a horizontal line at $S_{\text{Max}}$ amplitude between the $f_L$ and $f_U$ endpoints. Construct temporary points one decade below and one decade to the side of **Points 1** and **2**. Draw lines through these temporary points from **Point 1** and **Point 2** to the upper (**Point 3**) and lower (**Point 4**) frequency extremes of the plot as shown below.

![Graph showing SMax construction](image2)

An $S_{\text{Max}}$ power plot is drawn with slopes of $-1$, $0$ and $+1$.

Finally, draw a *Maximum Current* spectrum by drawing a horizontal line at amplitude $I_{\text{max}}$ from the graph’s maximum frequency to **Point 1** at $f_U$. Then raw a construction point two decades to the left and one decade below **Point 1**, as shown above. Draw a line from **Point 1** toward this temporary point. Stop the line at **Point 2**, the intersection with $f_L$. From **Point 2** construct a temporary point one decade to the left and one decade below **Point 2**. Draw a line from **Point 2** through this temporary construction point to the graph’s minimum frequency at **Point 3**.

![Graph showing IMax construction](image3)

An $I_{\text{Max}}$ plot is constructed with slopes of $+1$, $0$ and $+1/2$.
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All products purchased from High Energy Corporation are guaranteed to be free from defects of workmanship and material under normal use for a period of one year from the date of shipment.

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*Note: Product specifications are subject to change without notice.*
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