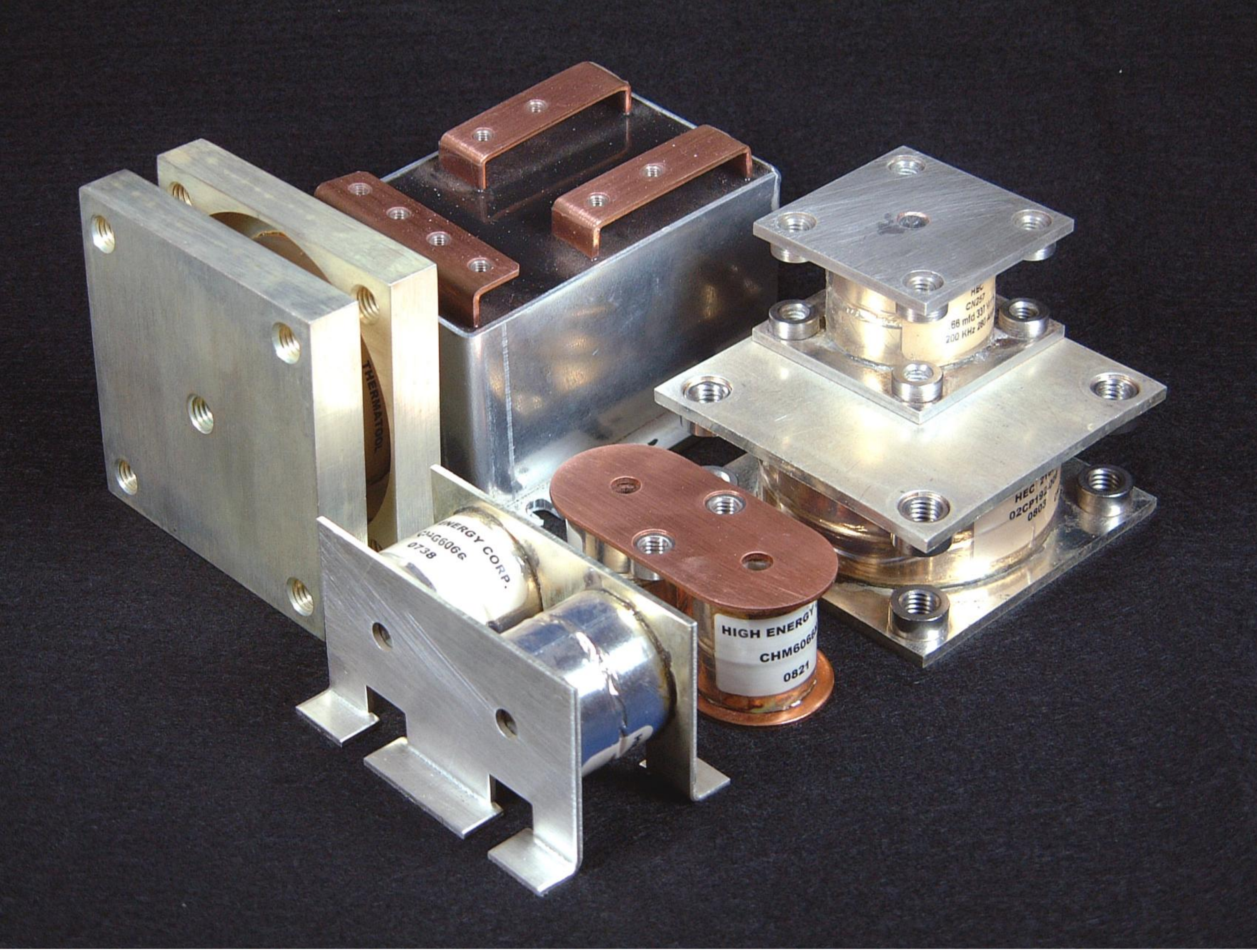

METALLIZED FILM CAPACITORS

High Voltage

High Current

High Frequency

HIGH ENERGY CORP.

Sales@HighEnergyCorp.com (610) 593-2800 FAX (610) 593-2985

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

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Contents

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.

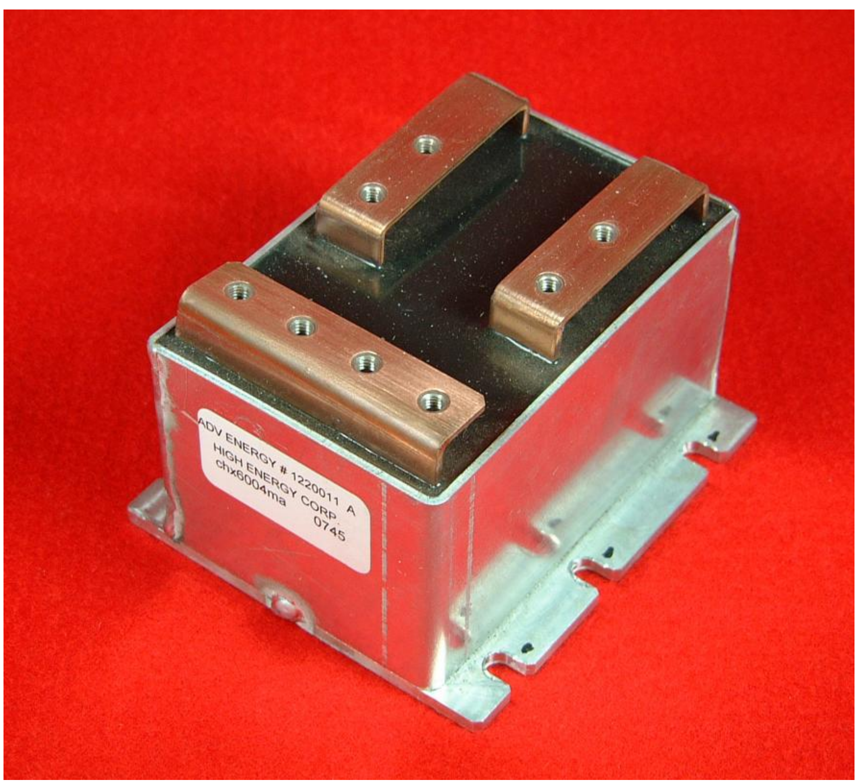
Note: Product specifications are subject to change without notice.

http://www.highenergycorp.com

HIGH ENERGY CORP.

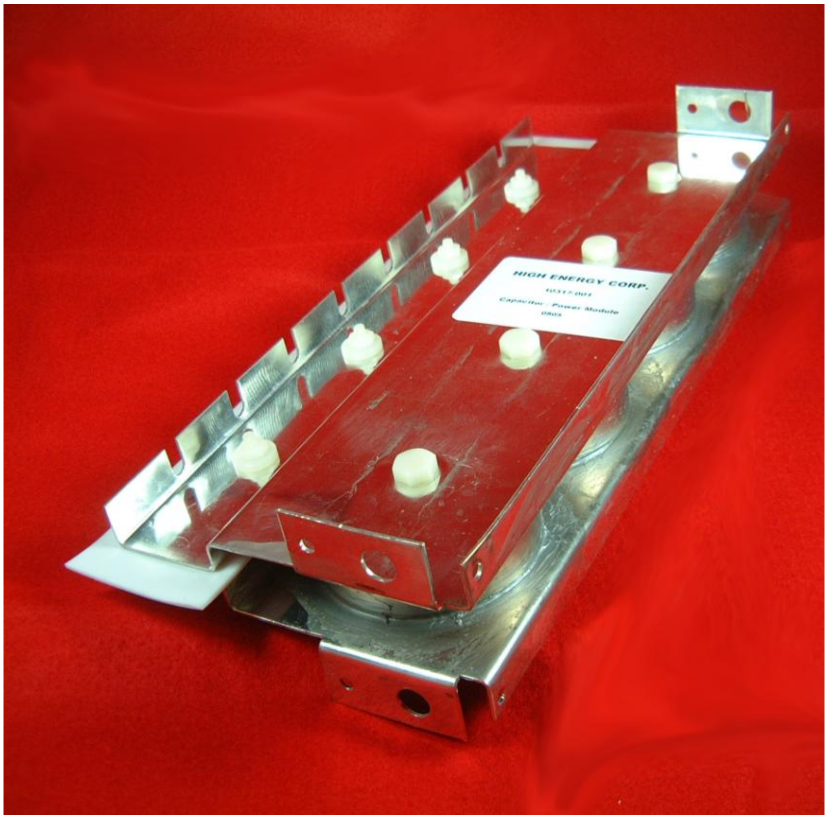
P.O. Box 308 Lower Valley Road Parkesburg, PA 19365

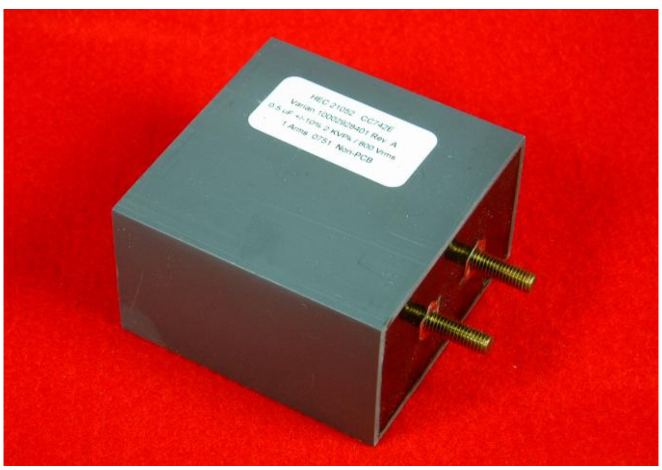
In today's 'modern' business climate, companies tend to provide products that fit the general needs of the industry they serve and to avoid deviating from these popular offerings. However, such 'blister-pack' solutions don't always serve the customer well. **High Energy Corporation** takes a different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



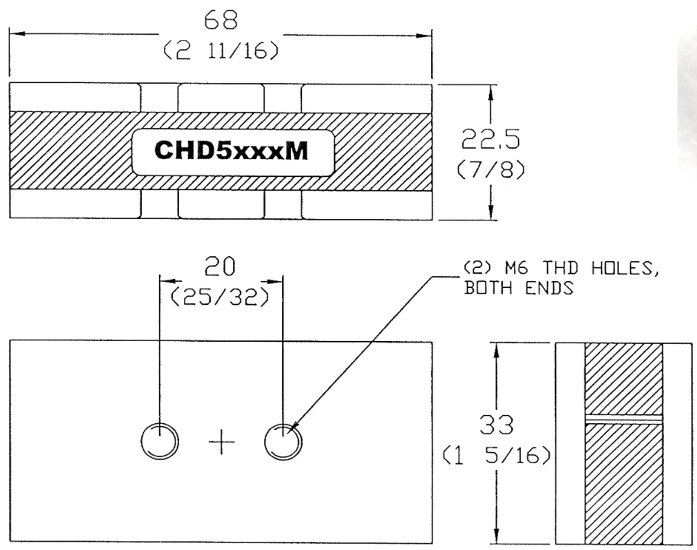
We are an Engineering managed and driven enterprise and we welcome the chance to partner with our customers and to bring our unique capabilities to bear upon the development, refinement and evolution of state-of-the-art metallized film capacitors. Whether your needs are for a simple custom value in one 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_{RMS} Working Voltage**
- **150 kVA Max Power**
- **250 A_{RMS} Max Current**
- **Conduction Cooled**
- **Series & Parallel Stackable**



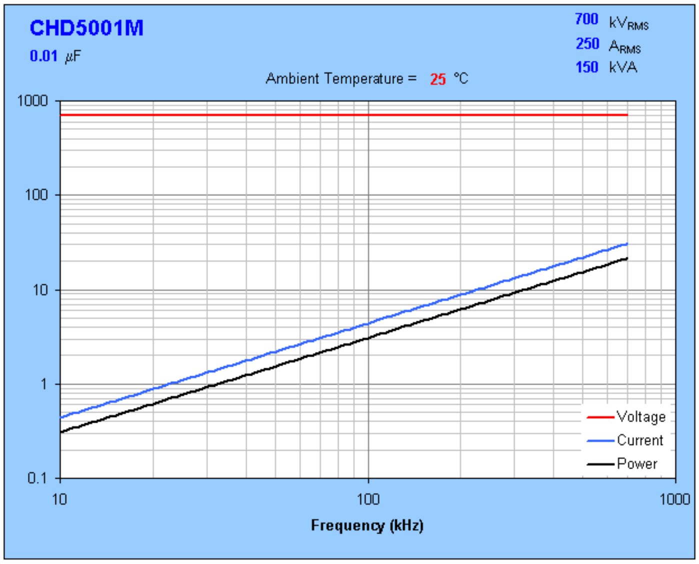
GENERAL SPECIFICATIONS

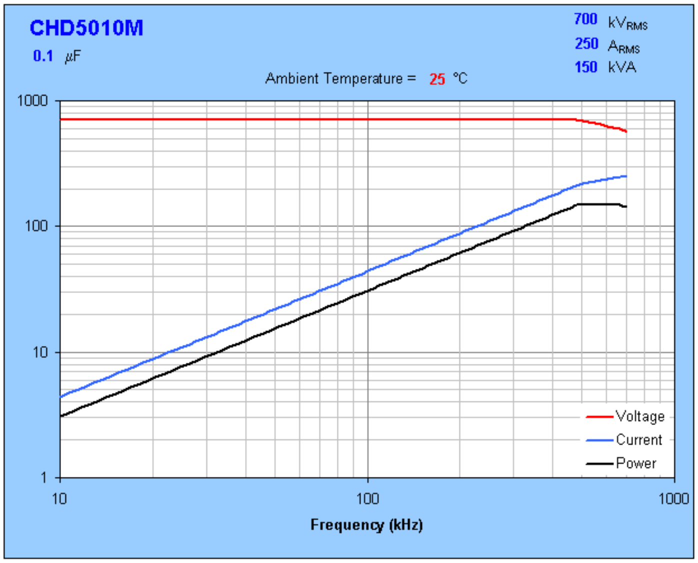
Capacitance Range	0.1 to 0.2 µF standard; 0.01 to 0.33 custom
Capacitance Tolerance	± 10% standard, other tolerances available
Dimensions	68 x 33 x 22.5 mm 2 $^{11}/_{16}$ x 1 $^{5}/_{32}$ x $^{7}/_{8}$ inch
Weight	0.2 kg; .44 lb
Operating Temperature	Up to +90° C
Cooling method	Conduction-cooled by bus bars
Dissipation Factor	0.1% Maximum
Stray Inductance	less than 5 nH

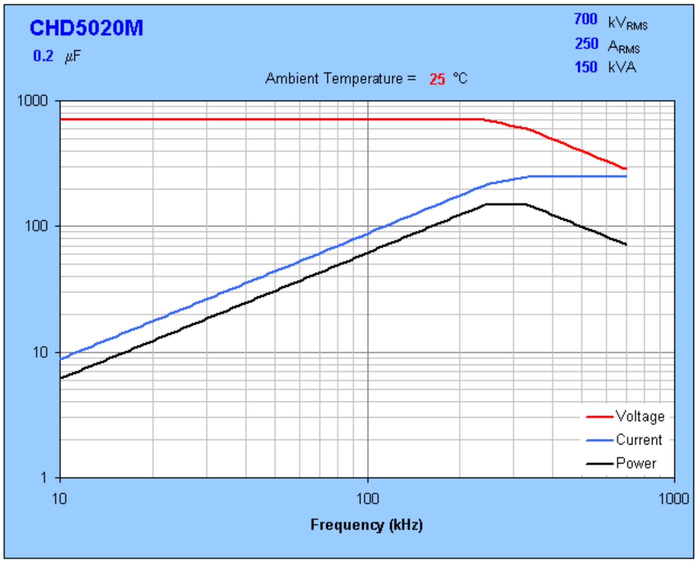
CAP (µF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	PART NUMBER
0.01	**700**	4868	**150**	6624	**250**	**700**	CHD5001M
0.1	**700**	487	**150**	662	**250**	**700**	CHD5010M
0.2	**700**	243	**150**	331	**250**	**700**	CHD5020M
0.33	**700**	148	**150**	201	**250**	**500**	CHD5330M

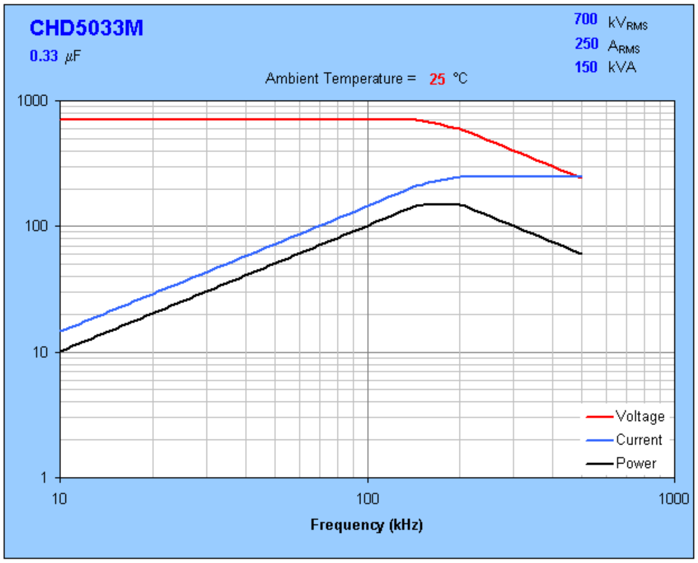
Custom capacitance values are available upon request.

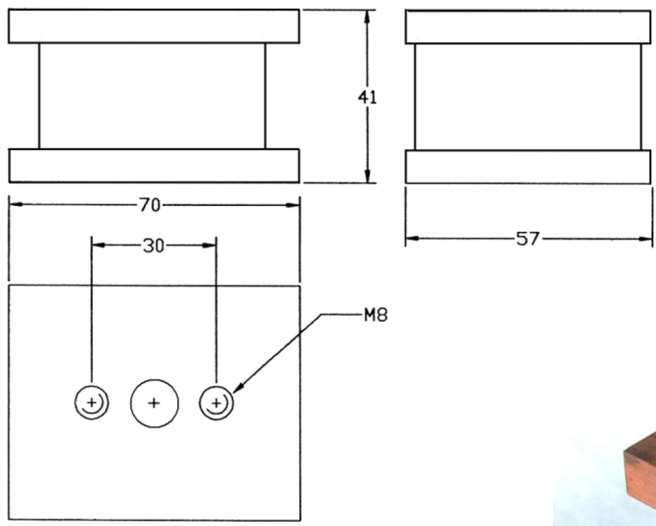
Typical Maximum Rating Curves for CHD Series Capacitors



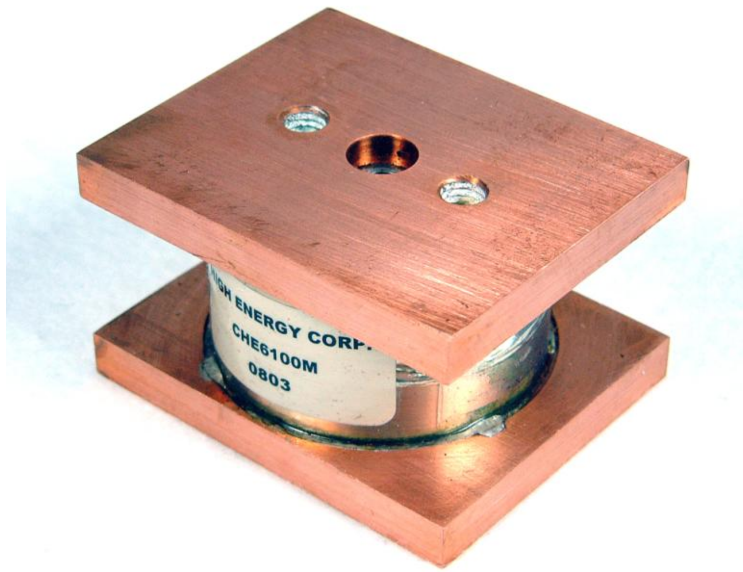








- Up to 700 V_{RMS} Working Voltage
- Up to 400 kVA Max Power
- Up to 800 A_{RMS} Max Current
- Conduction Cooled
- Series & Parallel Stackable



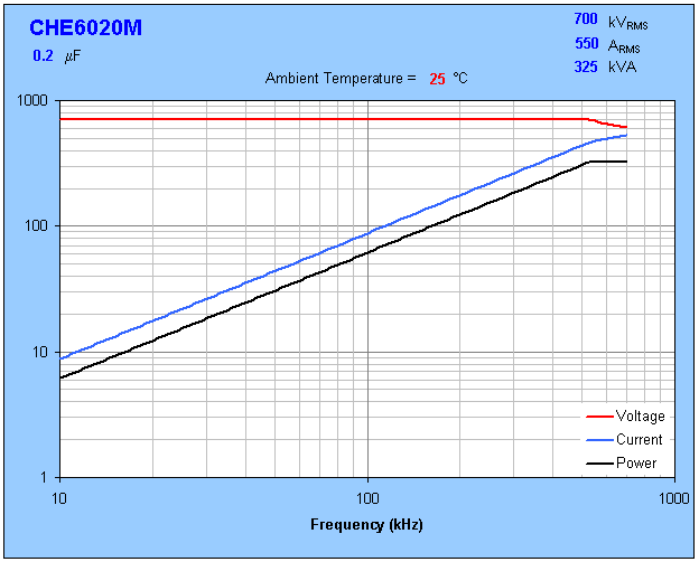
GENERAL SPECIFICATIONS

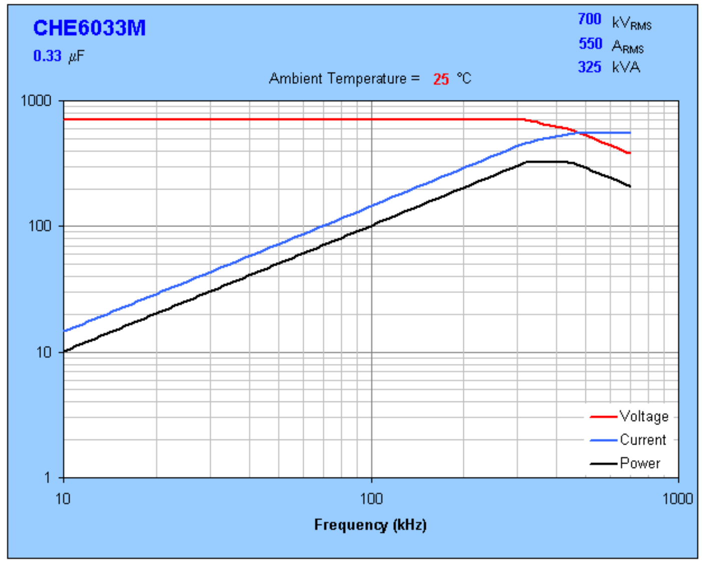
Capacitance Range	0.2 to 2.0 µF standard; 0.01 to 0.33 custom
Capacitance Tolerance	± 10% standard, other tolerances available
Dimensions	70 x 57 x 41 mm 2 $^{3}/_{4}$ x 2 $^{1}/_{4}$ x 2 $^{5}/_{8}$ inch
Weight	0.5 kg; 1.1 lb
Operating Temperature	Up to +90° C
Cooling method	Conduction-cooled by bus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

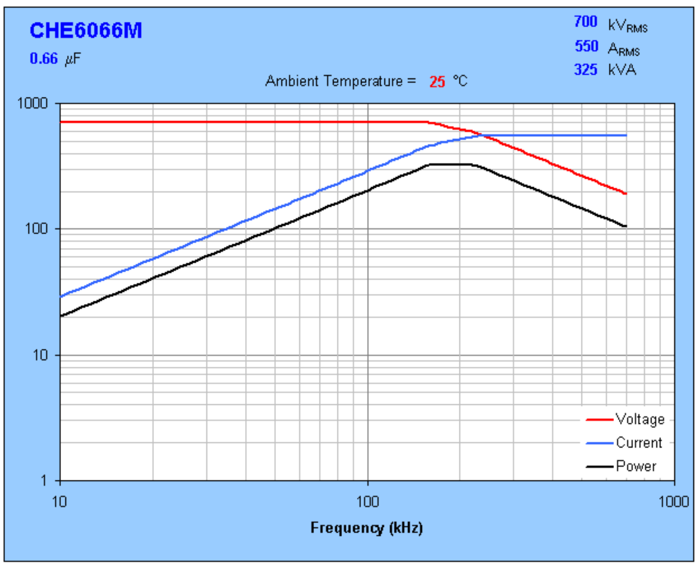
CAP (µF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	PART NUMBER
0.2	**700**	527	**325**	740	**550**	**700**	CHE6020M
0.33	**700**	320	**325**	448	**550**	**700**	CHE6033M
0.66	**700**	160	**325**	224	**550**	**700**	CHE6066M
1.0	**600**	177	**400**	224	**750**	**700**	CHE6100M
1.5	**525**	154	**400**	170	**800**	**700**	CHE6150M
2.0	**525**	115	**400**	127	**800**	**700**	CHE6200M

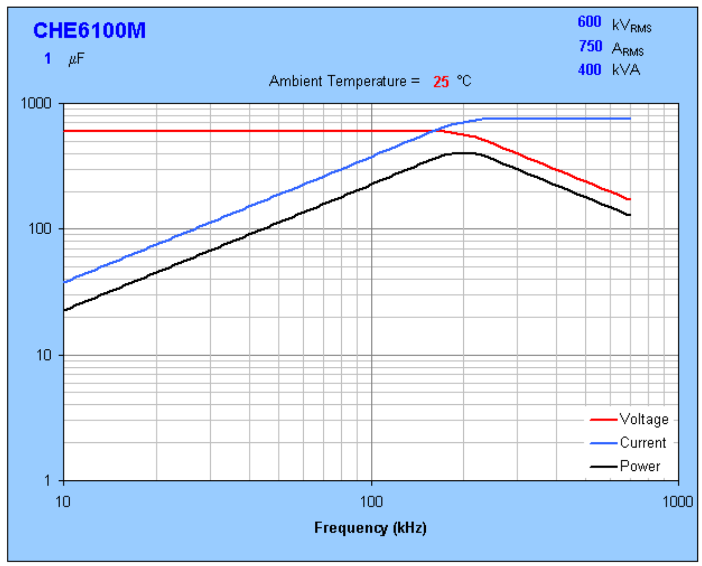
Custom capacitance values are available upon request.

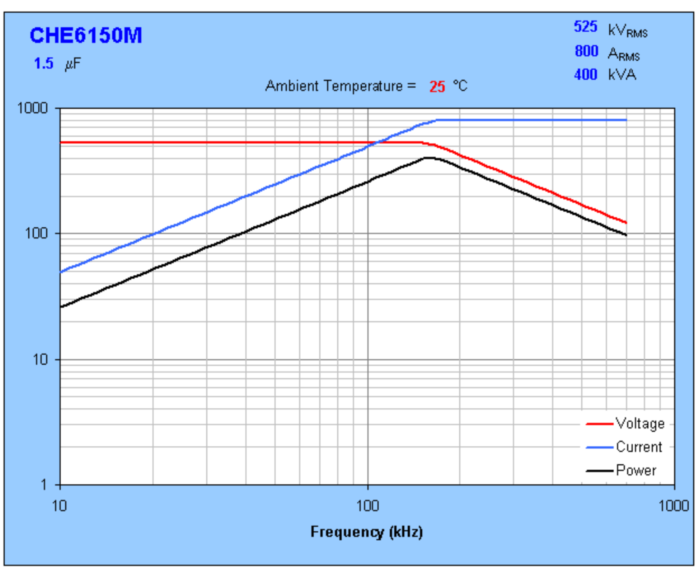
Typical Maximum Rating Curves for CHE Series Capacitors

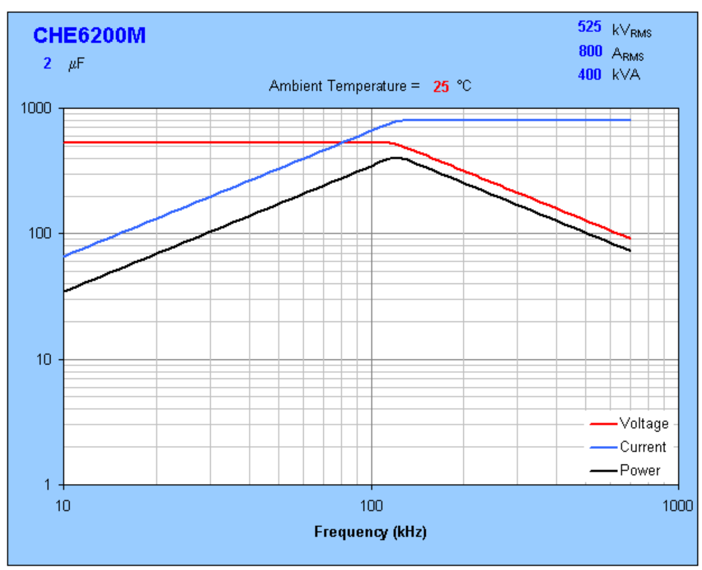




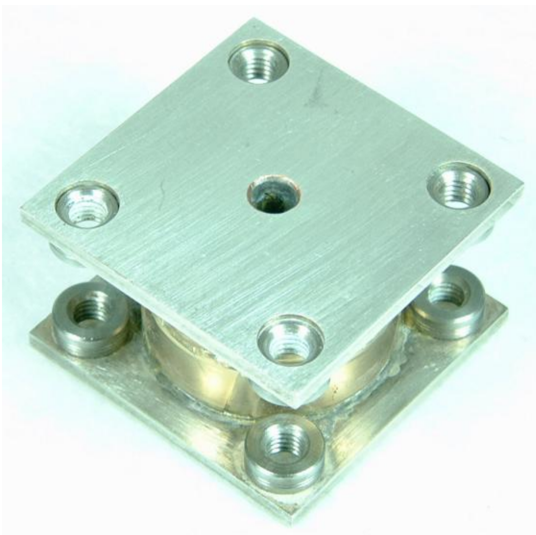


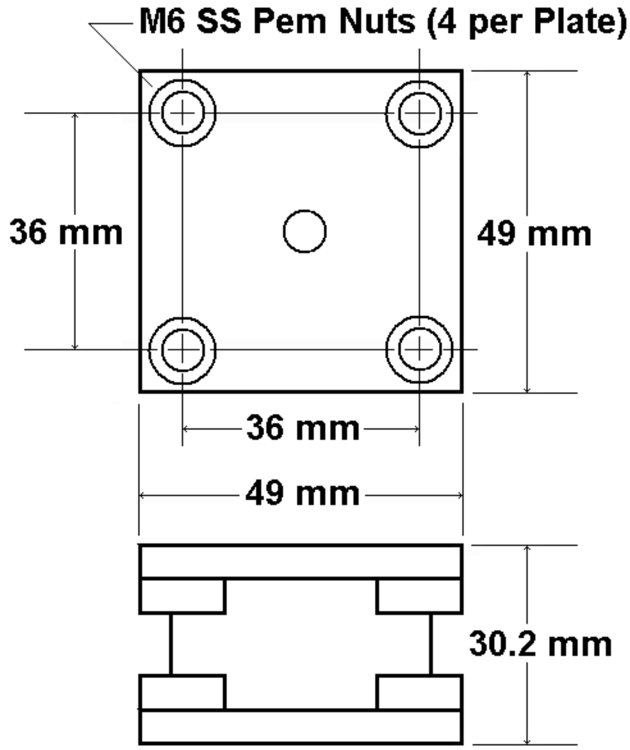






- Up to 700 V_{RMS} Working Voltage
- 600 kVA Max Power
- Up to 525 A_{RMS} Max Current
- Conduction Cooled
- Series & Parallel Stackable





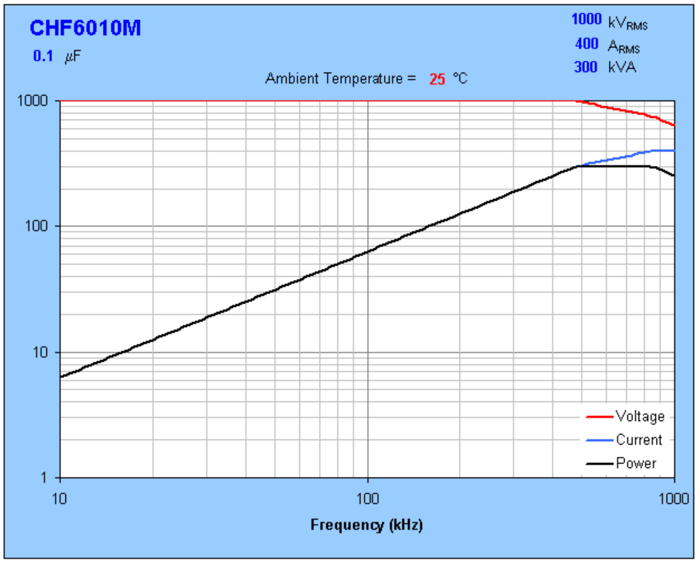
GENERAL SPECIFICATIONS

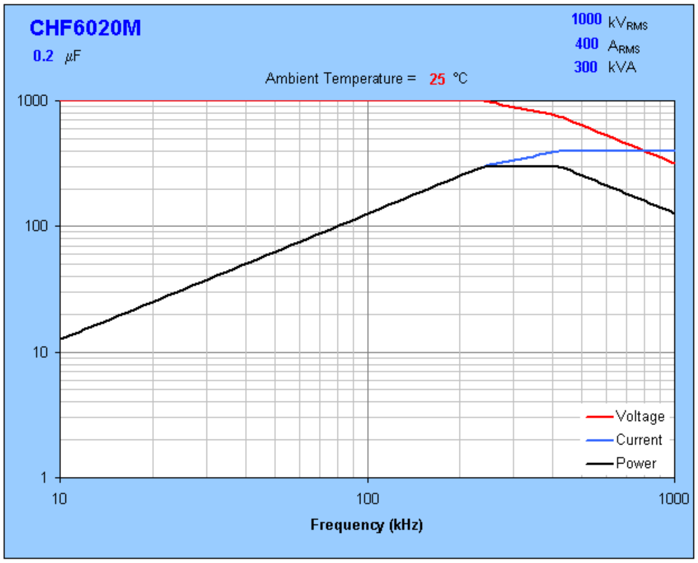
Capacitance Range	0.18 to 1.2 µF standard; 0.01 to 0.33 custom
Capacitance Tolerance	± 10% standard, other tolerances available
Dimensions	49 x 49 x 30 mm 1 15/16 x 1 15/16 x 1 3/16 inch
Weight	0.25 kg; 0.5 lb
Operating Temperature	Up to +90° C
Cooling method	Conduction-cooled by bus bars
Dissipation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

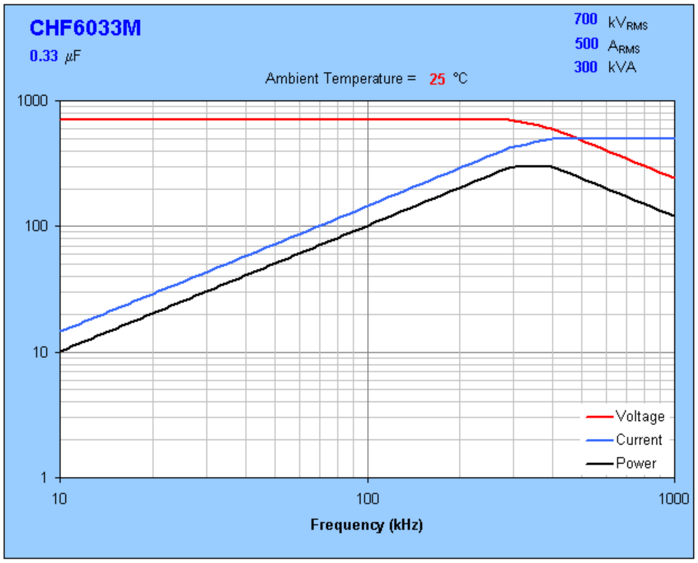
CAP (µF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	PART NUMBER
0.1	**1000**	477	**300**	848	**400**	**500**	CHF6010M
0.2	**700**	239	**300**	373	**400**	**500**	CHF6020M
0.33	**700**	295	**300**	401	**500**	**500**	CHF6033M
0.66	**600**	148	**300**	201	**500**	**500**	CHF6066M
1.0	**600**	133	**300**	224	**650**	**500**	CHF6100M
1.32	**500**	100	**300**	170	**650**	**300**	CHF6132M

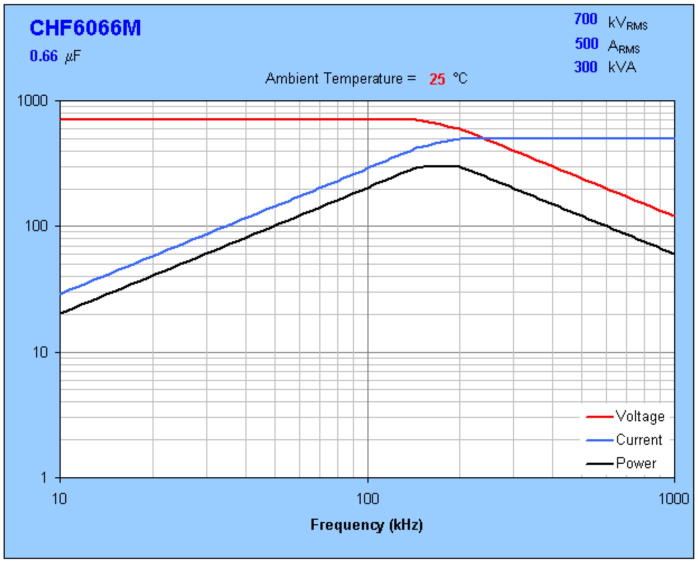
Custom capacitance values are available upon request.

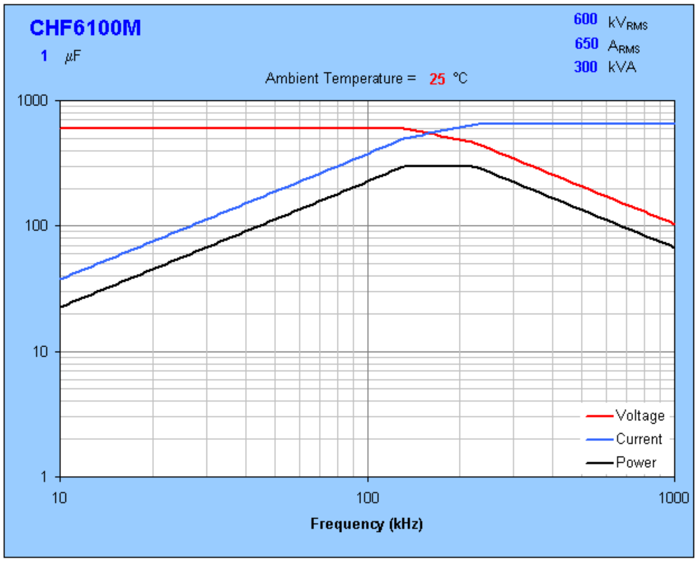
Typical Maximum Rating Curves for CHF Series Capacitors

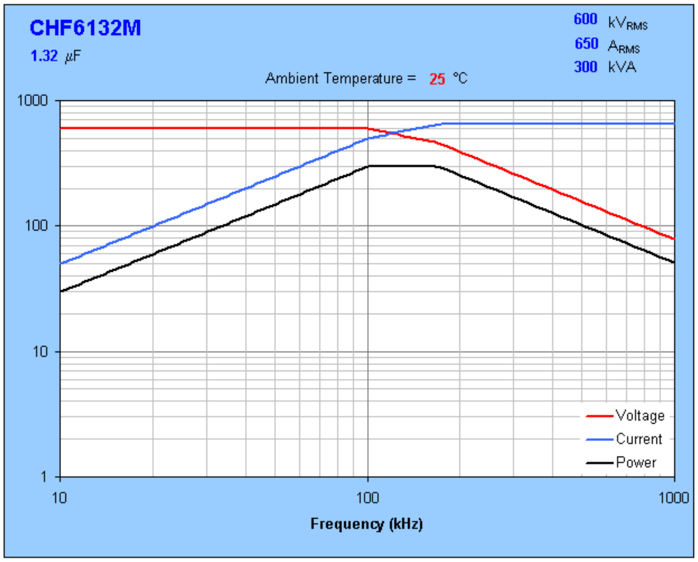




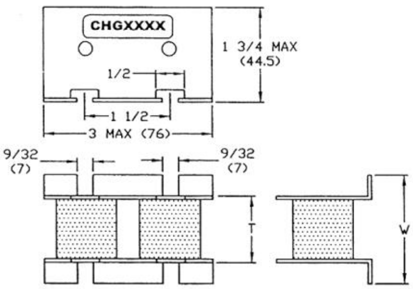




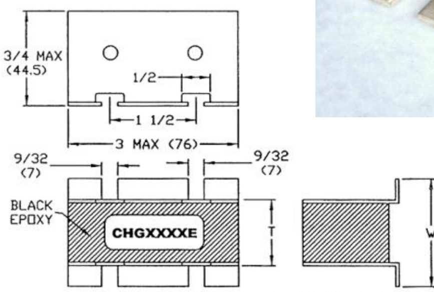




- **Up to 700 V_{RMS} Working Voltage**
- **Up to 375 kVA Max Power**
- **Up to 625 A_{RMS} Max Current**
- **Conduction Cooled**
- **Series & Parallel Stackable**



STANDARD CHG SERIES



EPOXIED CHG SERIES (E)

SERIES	T	W
CHG5	7/8 (22.2)	1 11/16 (42.8)
CHG6	1 3/16 (30.2)	2 (51)

GENERAL SPECIFICATIONS

Capacitance Range 0.11 to 2.4 µF

Capacitance Tolerance ± 10% standard, other tolerances available

Dimensions **CHG5 –** 76.2 x 37.8 x 39.2 (mm) / 3 x 1 $^{11}/_{16}$ x 1 $^{3}/_{4}$ (inch) **CHG6 –** 76.2 x 50.8 x 39.2 / 3 x 2 x 1 $^{3}/_{4}$

Weight **CHG5 –** 0.14 (kg) / 0.30 (lb) **CHG6 –** 0.23 / 0.50

Operating Temperature Up to +90° C

Cooling method Conduction-cooled by bus bars

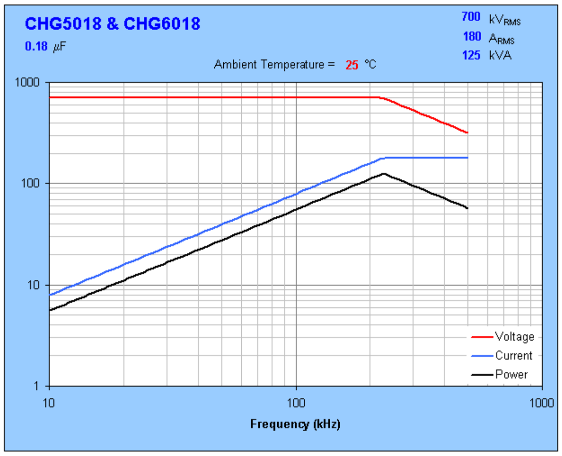
Dissipation Factor 0.1% Maximum

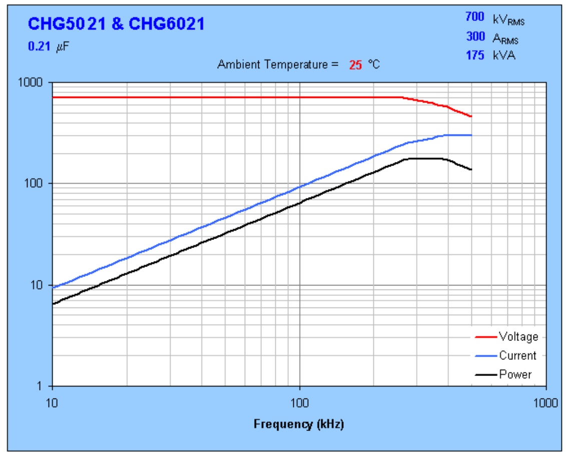
Stray Inductance less than 5 nH

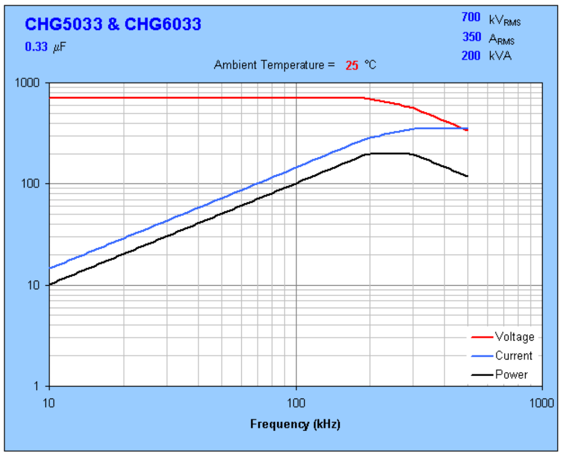
CAP (µF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	Value Available In CHG5 Size	PART NUMBER
0.11	**700**	369	**125**	375	**180**	**500**	√	CHG6018
0.21	**700**	270	**175**	389	**300**	**500**	√	CHG6021
0.33	**700**	197	**200**	295	**350**	**500**	√	CHG6033
0.51	**650**	203	**275**	283	**500**	**500**	√	CHG6051
0.66	**600**	218	**325**	290	**625**	**500**	√	CHG6066
1.2	**500**	106	**200**	106	**400**	**500**		CHG6120
2.4	**400**	83	**200**	83	**500**	**500**		CHG6240

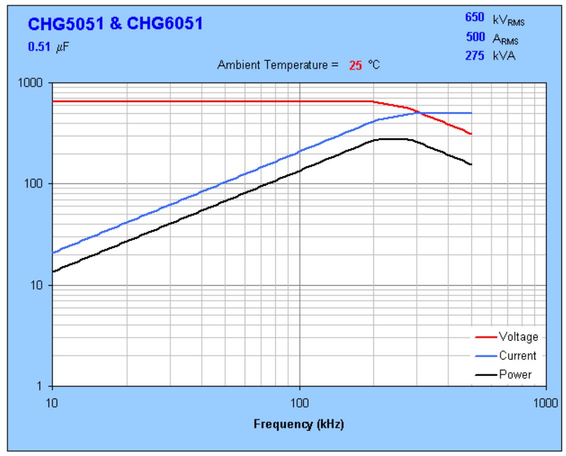
Add suffix **E** for (as in CHG5018ME) for epoxy-potted part.
Custom capacitance values are available upon request.

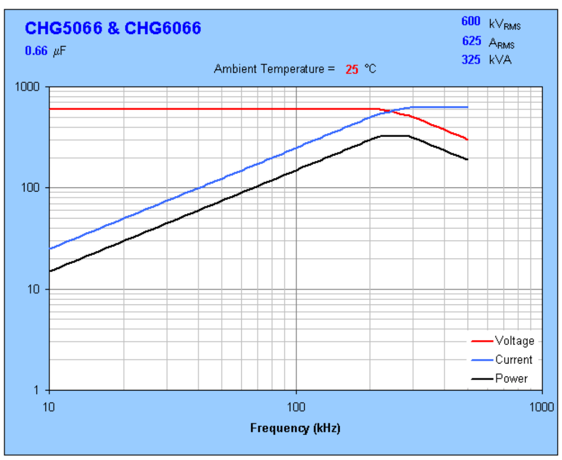
Typical Maximum Rating Curves for CHG Series Capacitors

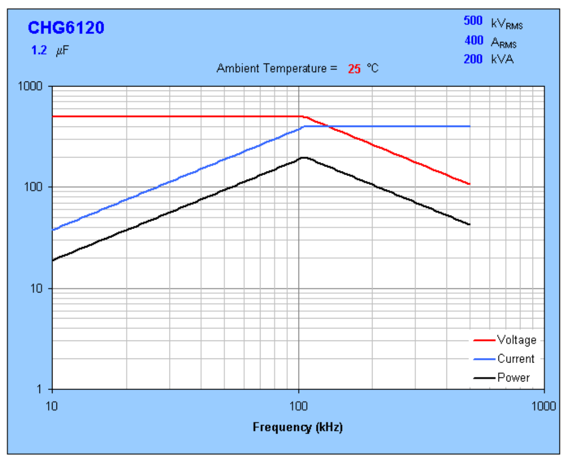


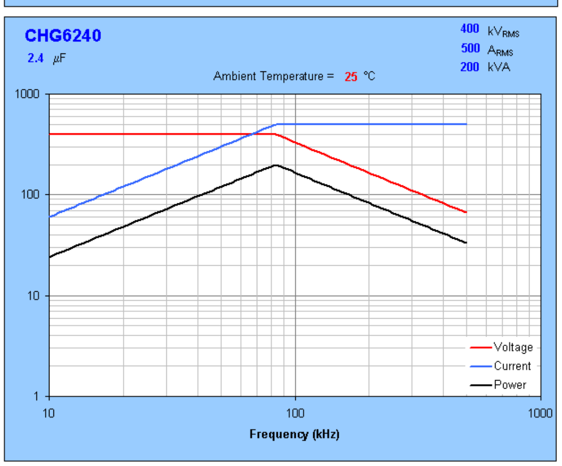




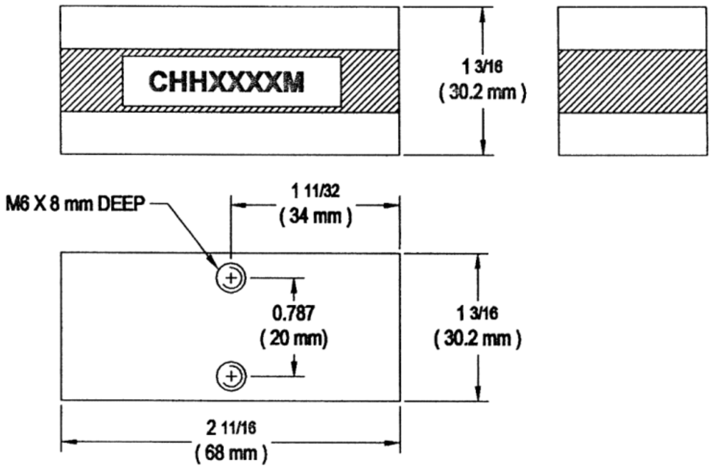








- **Up to 700 V_{RMS} Working Voltage**
- **160 kVA Max Power**
- **Up to 625 A_{RMS} Max Current**
- **Conduction Cooled**
- **Series & Parallel Stackable**

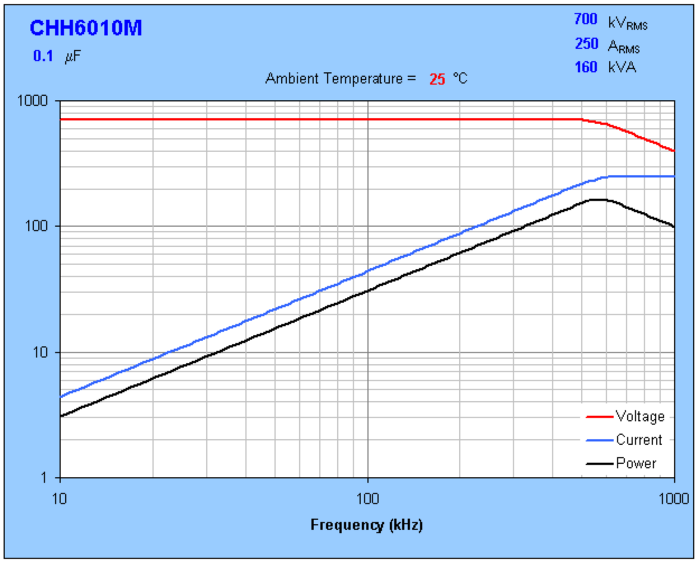


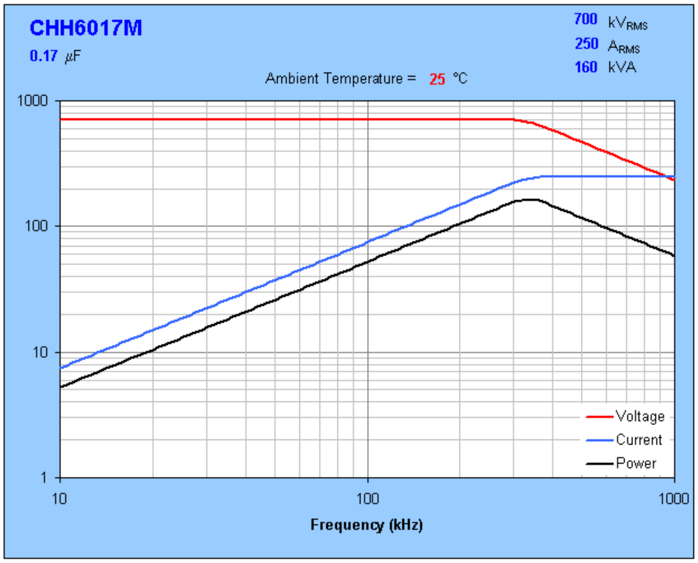
GENERAL SPECIFICATIONS

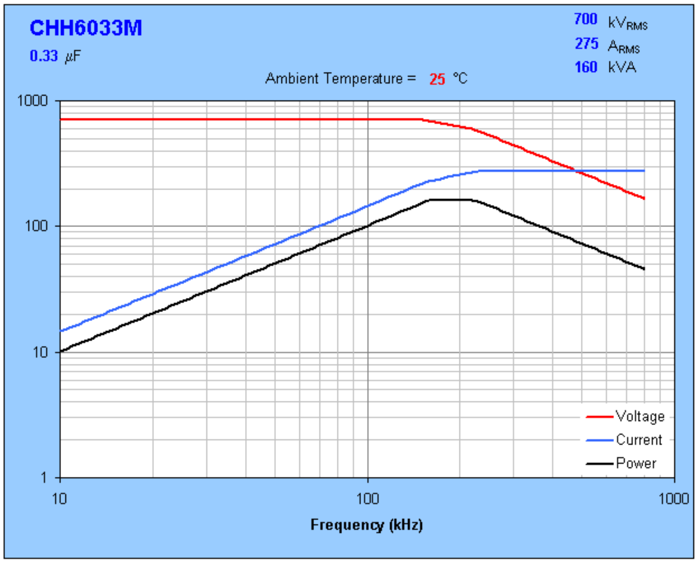
Capacitance Range	0.1 to 2.5 µF standard; 0.01 to 0.33 custom
Capacitance Tolerance	± 10% standard, other tolerances available
Dimensions	68 x 30.2 x 30.2 mm 2 $^{11}/_{16}$ x 1 $^{3}/_{16}$ x 1 $^{3}/_{16}$ inch
Weight	0.5 kg; 1.1 lb
Operating Temperature	Up to +90° C
Cooling method	Conduction-cooled by bus bars
Dissipation Factor	0.1% Maximum
Stray Inductance	less than 5 nH

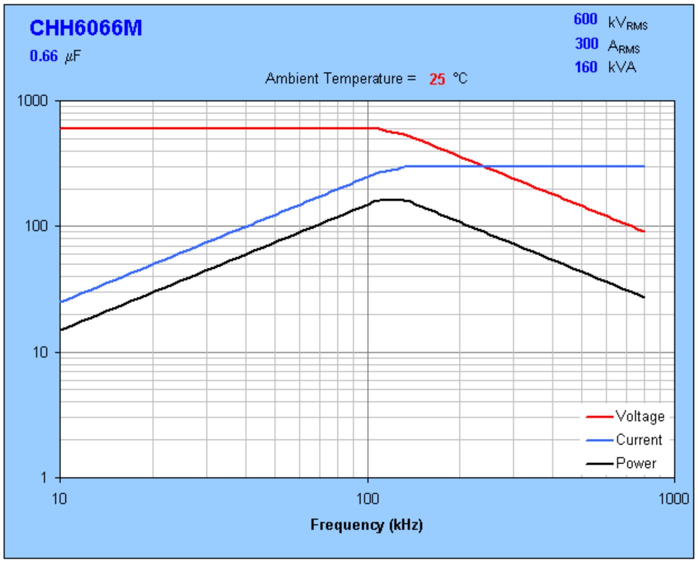
CAP (µF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	PART NUMBER
0.1	**700**	519	**160**	621	**250**	**1000**	CHH6010M
0.17	**700**	305	**160**	365	**250**	**1000**	CHH5017M
0.33	**700**	157	**160**	228	**275**	**800**	CHH6033M
0.66	**600**	107	**160**	135	**300**	**800**	CHH6066M
1.2	**500**	85	**160**	87	**325**	**800**	CHH6120M
2.5	**400**	64	**160**	64	**400**	**800**	CHH6250M

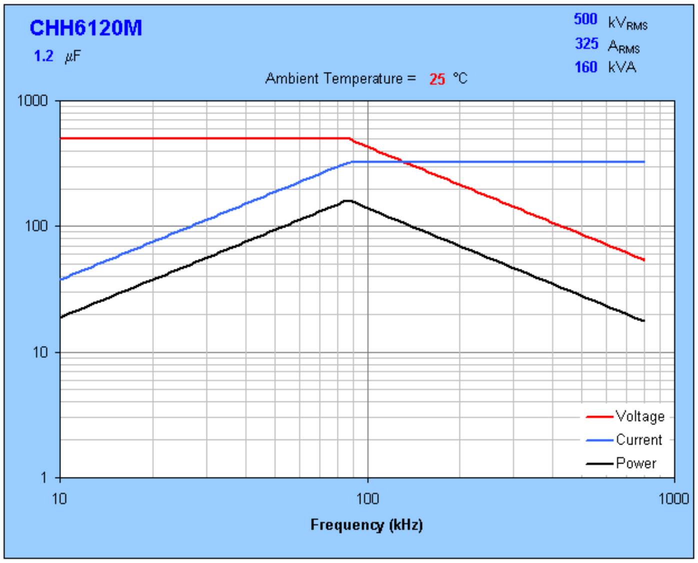
Custom capacitance values are available upon request.

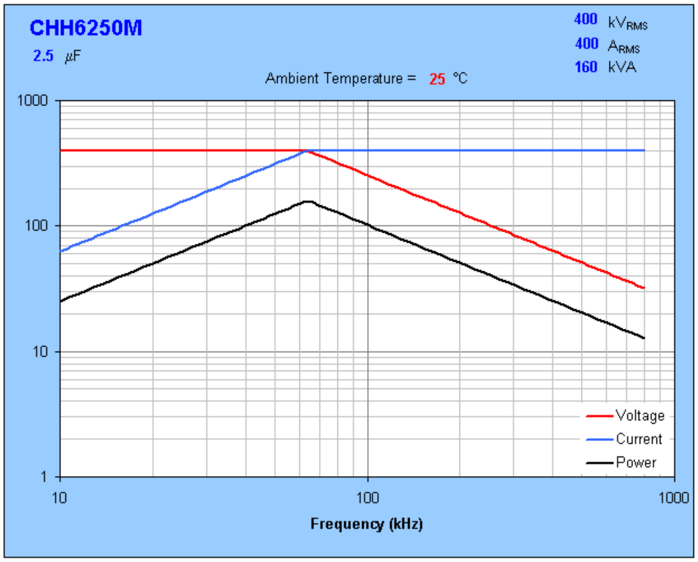

CHH6010M
0.1 μF
700 kVRMS
250 ARMS
160 kVA
Ambient Temperature = 25 °C
Voltage
Current
Power
Frequency (kHz)


CHH6017M
0.17 μF
700 kVRMS
250 ARMS
160 kVA
Ambient Temperature = 25 °C
Voltage
Current
Power
Frequency (kHz)

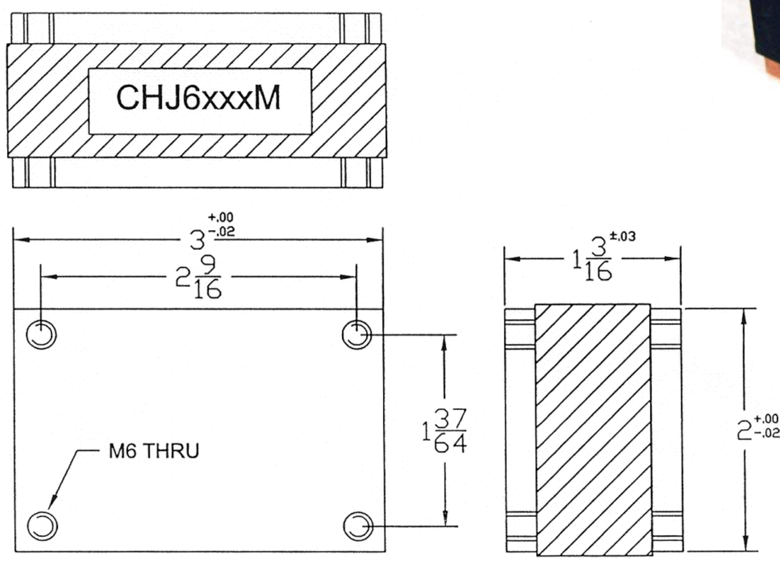

CHH6033M
0.33 μF
700 kVRMS
275 ARMS
160 kVA
Ambient Temperature = 25 °C
Voltage
Current
Power
Frequency (kHz)


CHH6066M
0.66 μF
600 kVRMS
300 ARMS
160 kVA
Ambient Temperature = 25 °C
Voltage
Current
Power
Frequency (kHz)


CHH6120M
1.2 μF
500 kVRMS
325 ARMS
160 kVA
Ambient Temperature = 25 °C
Voltage
Current
Power
Frequency (kHz)


CHH6250M
2.5 μF
400 kVRMS
400 ARMS
160 kVA
Ambient Temperature = 25 °C
Voltage
Current
Power
Frequency (kHz)

- **Up to 700 V_{RMS} Working Voltage**
- **Up to 210 kVA Max Power**
- **Up to 600 A_{RMS} Max Current**
- **Conduction Cooled**
- **Series & Parallel Stackable**



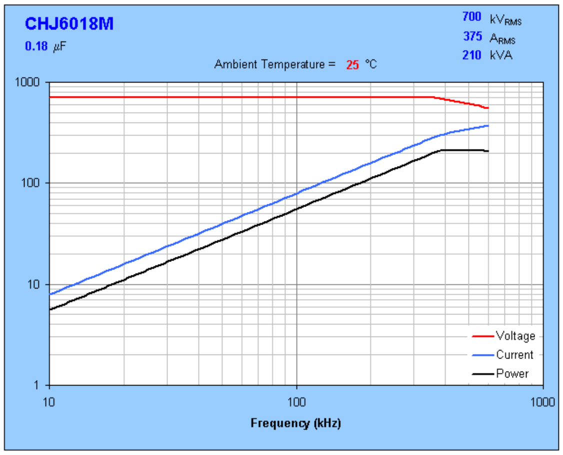
GENERAL SPECIFICATIONS

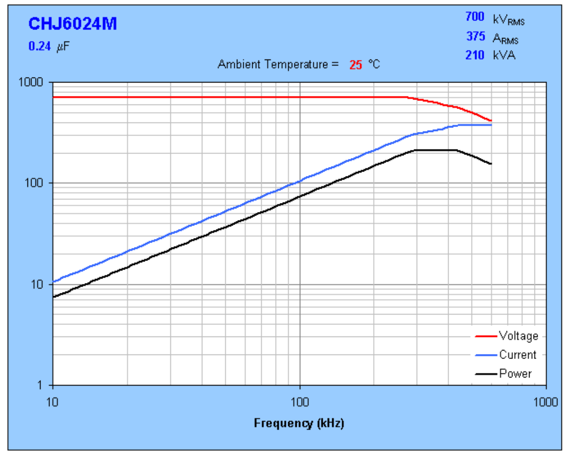
Capacitance Range	0.18 to 5.0 μF standard; 0.01 to 0.33 custom
Capacitance Tolerance	± 10% standard, other tolerances available
Dimensions	76.2 x 50.8 x 36.5 mm 3 x 2 x 1 7/16 inch
Weight	0.27 kg; 0.6 lb
Operating Temperature	Up to +90° C
Cooling method	Conduction-cooled by bus bars
Dissipation Factor	0.1% Maximum
Stray Inductance	less than 5 nH

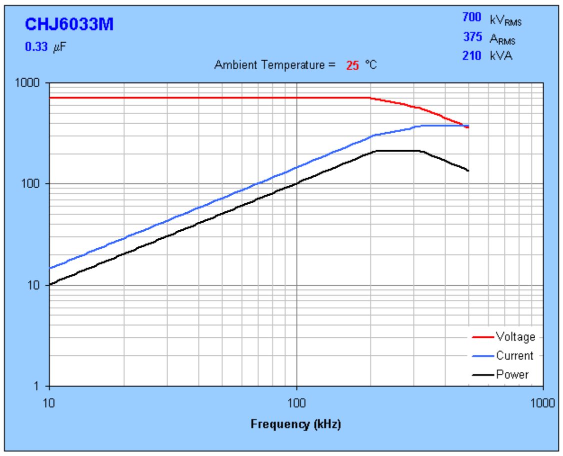
CAP (μF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	PART NUMBER
0.18	**700**	379	**210**	591	**375**	**600**	CHJ6018M
0.24	**700**	284	**210**	444	**375**	**600**	CHJ6024M
0.33	**700**	207	**210**	323	**375**	**600**	CHJ6033M
0.66	**600**	141	**210**	259	**475**	**500**	CHJ6066M
1.2	**500**	111	**210**	174	**525**	**300**	CHJ6120M
2.4	**400**	83	**200**	91	**525**	**300**	CHJ6240M
5.0	**300**	64	**180**	64	**600**	**300**	CHJ6500M

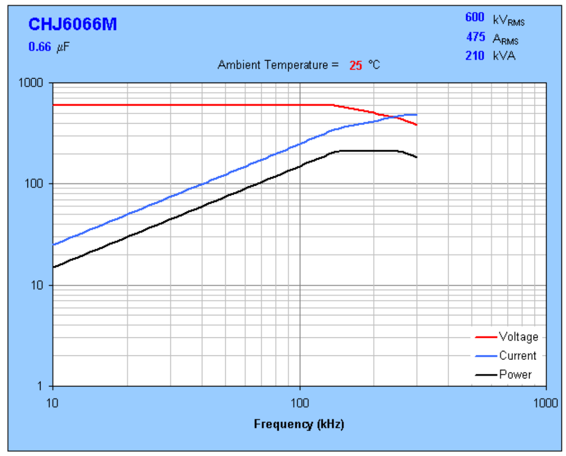
Custom capacitance values are available upon request.

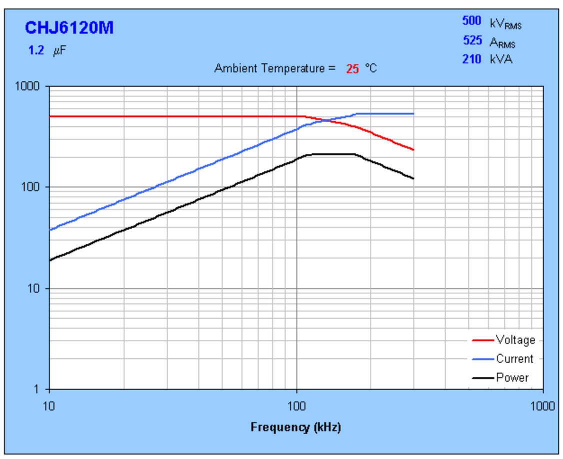
Typical Maximum Rating Curves for CHJ Series Capacitors

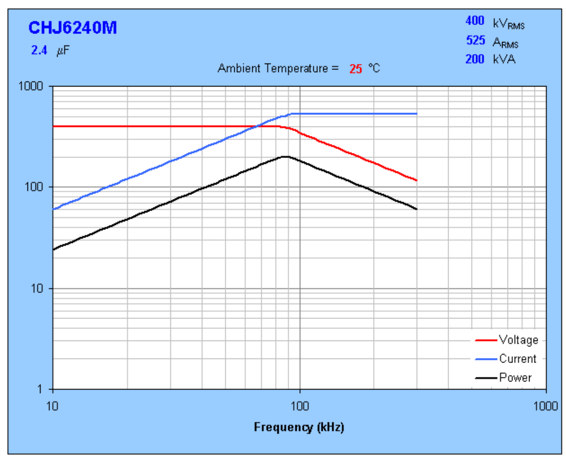


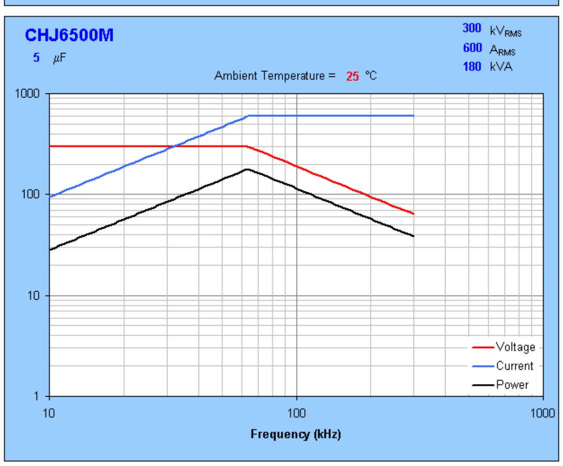




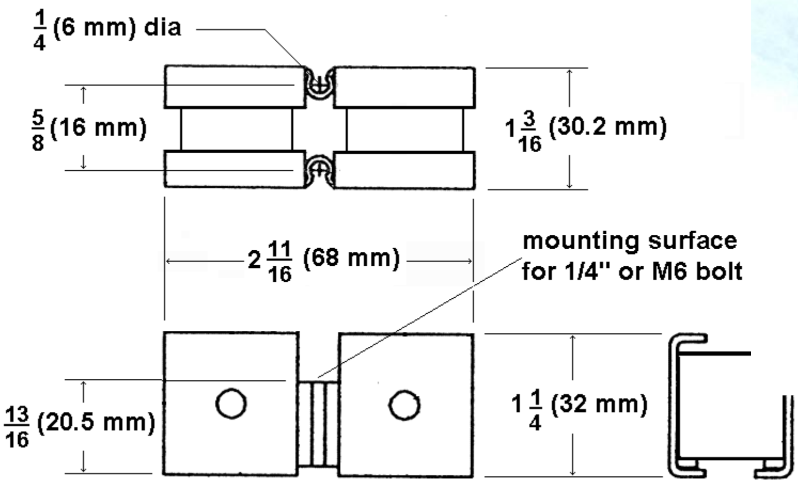


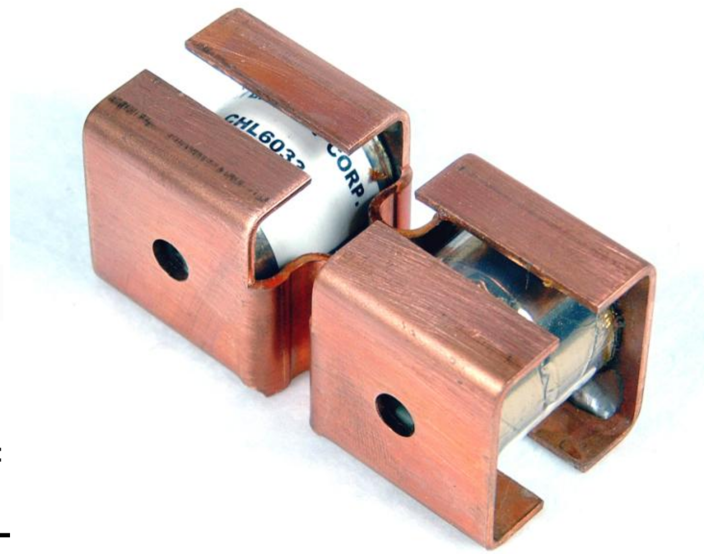






- **Up to 700 V_{RMS} Working Voltage**
- **160 kVA Max Power**
- **Up to 400 A_{RMS} Max Current**
- **Conduction Cooled**
- **Series & Parallel Stackable**





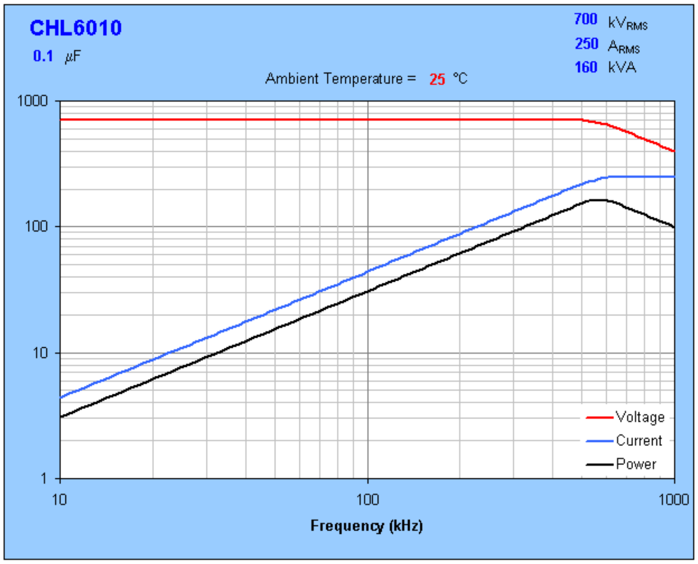
GENERAL SPECIFICATIONS

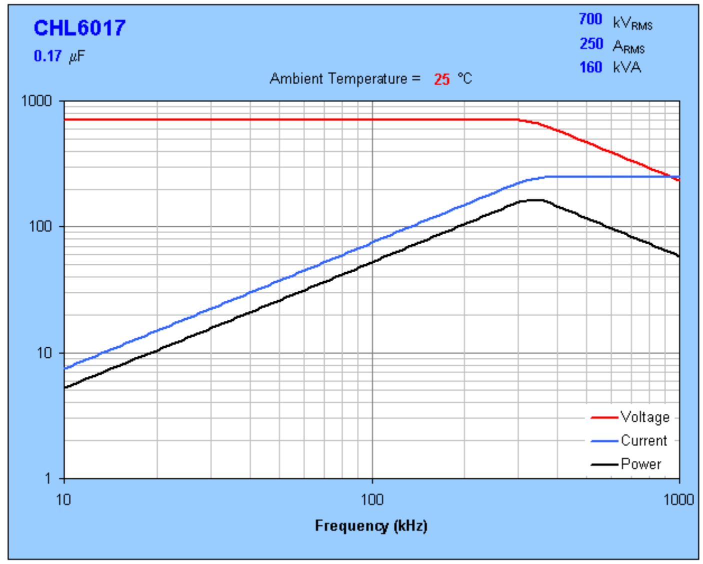
Capacitance Range	0.1 to 2.5 µF standard; 0.01 to 0.33 custom
Capacitance Tolerance	± 10% standard, other tolerances available
Dimensions	68 x 32 x 30.2 mm 2 $^{11}/_{16}$ x 1 $^{1}/_{4}$ x 1 $^{3}/_{16}$ inch
Weight	0.5 kg; 1.1 lb
Operating Temperature	Up to +90° C
Cooling method	Conduction-cooled by bus bars
Dissipation Factor	0.1% Maximum
Stray Inductance	less than 5 nH

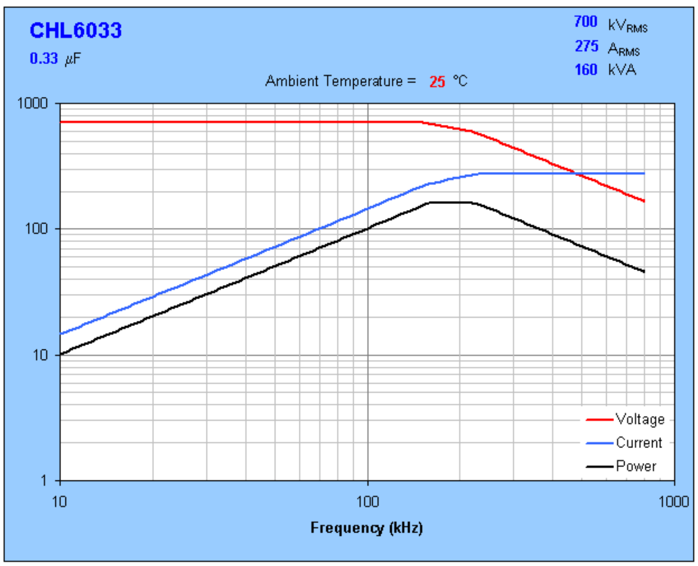
CAP (µF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	PART NUMBER
0.1	**700**	519	**160**	621	**250**	**1000**	CHL6010
0.17	**700**	305	**160**	365	**250**	**1000**	CHL6017
0.33	**700**	157	**160**	228	**275**	**800**	CHL6033
0.66	**600**	107	**160**	135	**300**	**800**	CHL6066
1.2	**500**	85	**160**	87	**325**	**800**	CHL6120
2.5	**400**	64	**160**	64	**400**	**800**	CHL6250

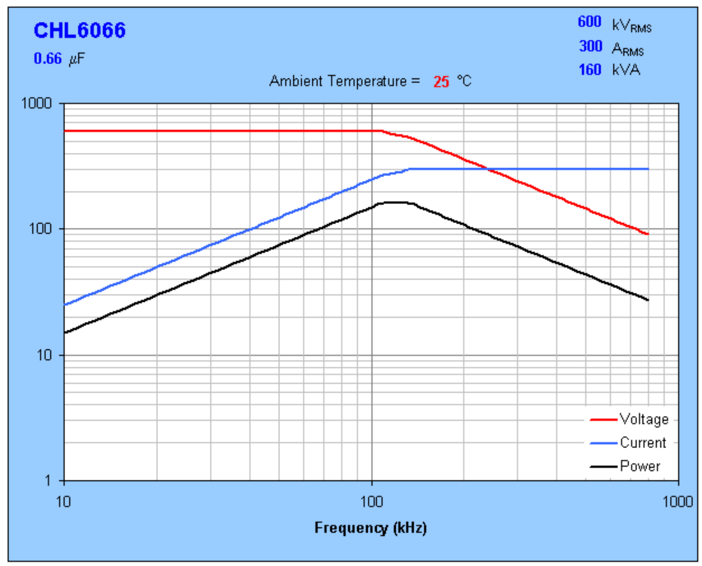
Custom capacitance values are available upon request.

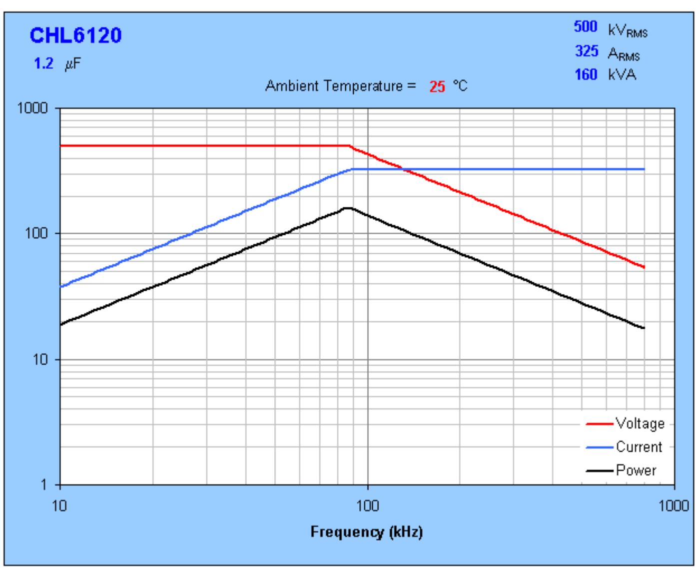
Typical Maximum Rating Curves for CHL Series Capacitors

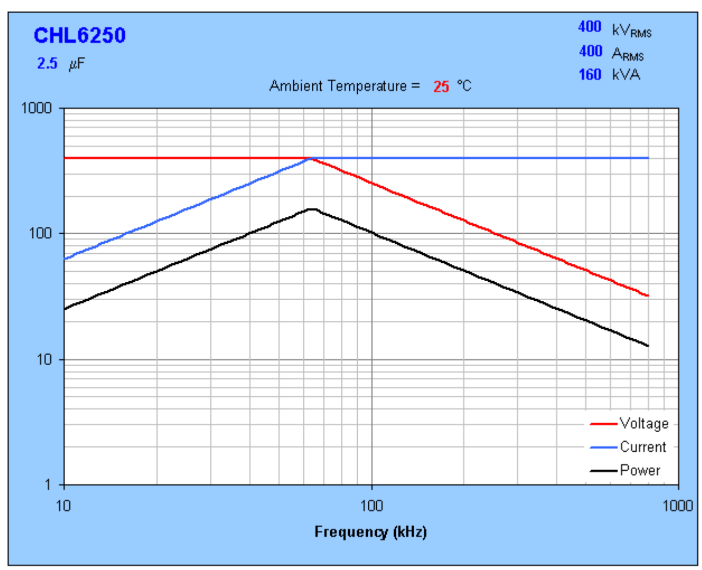




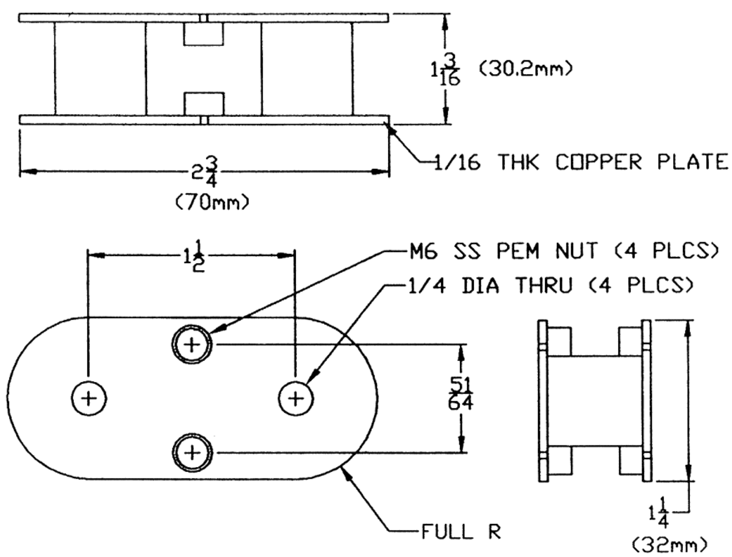








- **Up to 700 V_{RMS} Working Voltage**
- **160 kVA Max Power**
- **Up to 400 A_{RMS} Max Current**
- **Conduction Cooled**
- **Series & Parallel Stackable**



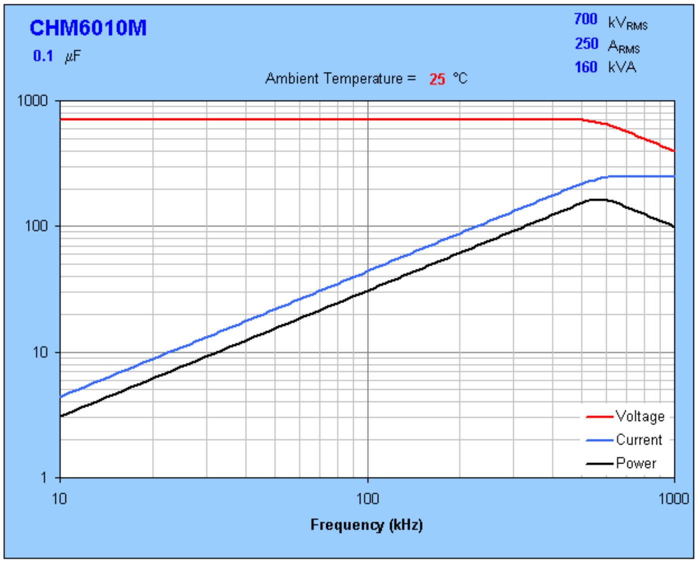
GENERAL SPECIFICATIONS

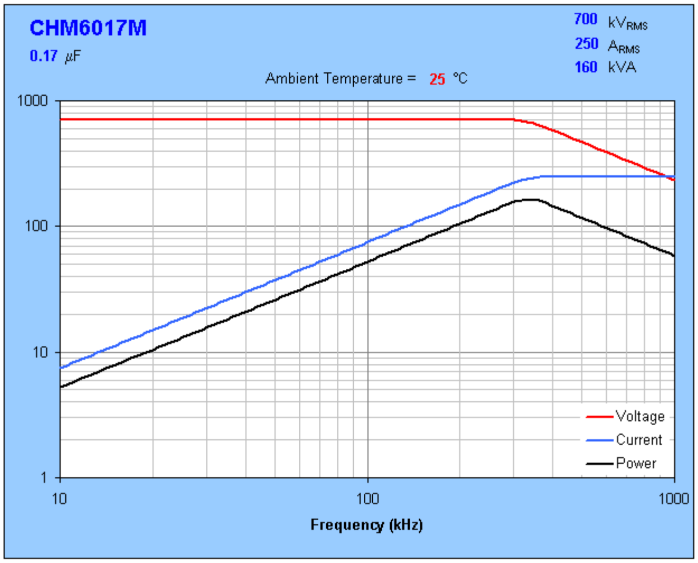
Capacitance Range	0.1 to 2.5 μF standard; 0.01 to 0.33 custom
Capacitance Tolerance	± 10% standard, other tolerances available
Dimensions	70 x 32 x 30.2 mm 2 $^3/_4$ x 1 $^1/_4$ x 1 $^3/_{16}$ inch
Weight	0.5 kg; 1.1 lb
Operating Temperature	Up to +90° C
Cooling method	Conduction-cooled by bus bars
Dissipation Factor	0.1% Maximum
Stray Inductance	less than 5 nH

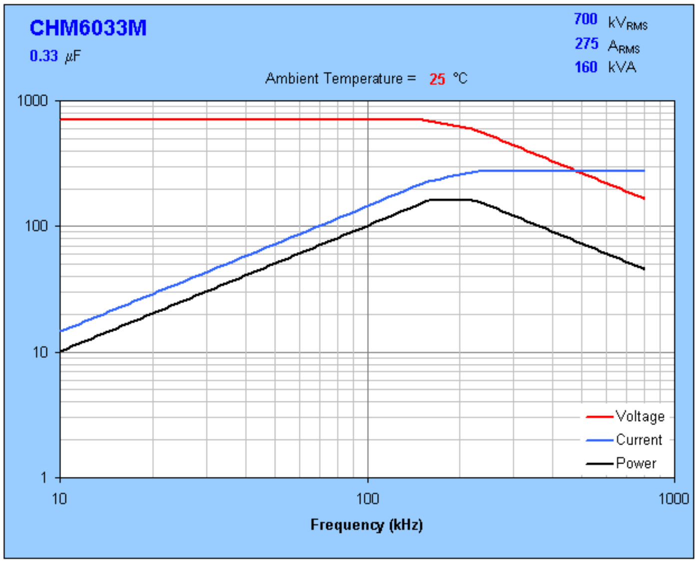
CAP (μF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	PART NUMBER
0.1	**700**	519	**160**	621	**250**	**1000**	CHM6010M
0.17	**700**	305	**160**	365	**250**	**1000**	CHM6017M
0.33	**700**	157	**160**	228	**275**	**800**	CHM6033M
0.66	**600**	107	**160**	135	**300**	**800**	CHM6066M
1.2	**500**	85	**160**	87	**325**	**800**	CHM6120M
2.5	**400**	64	**160**	64	**400**	**800**	CHM6250M

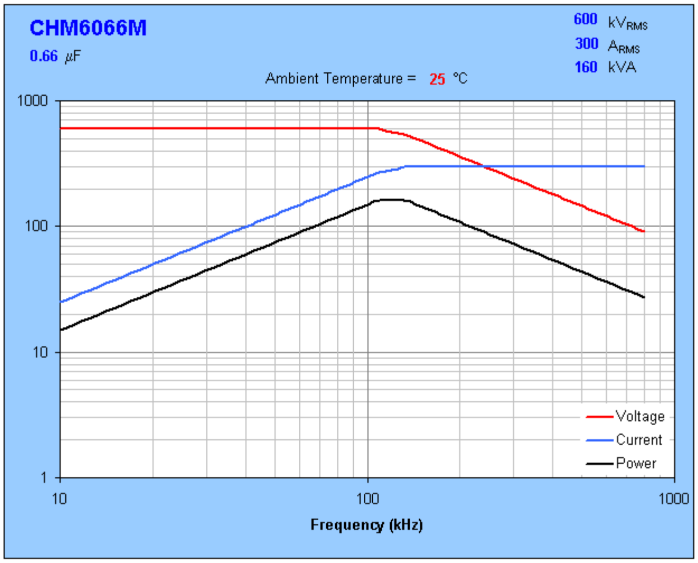
Custom capacitance values are available upon request.

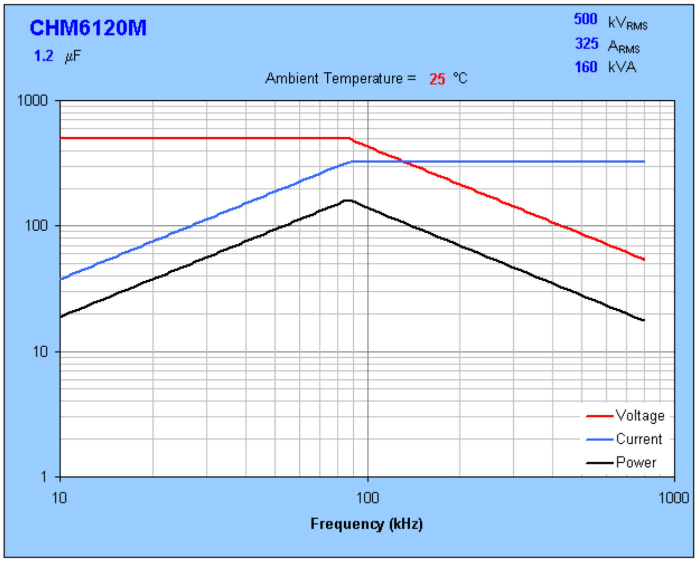
Typical Maximum Rating Curves for CHM Series Capacitors

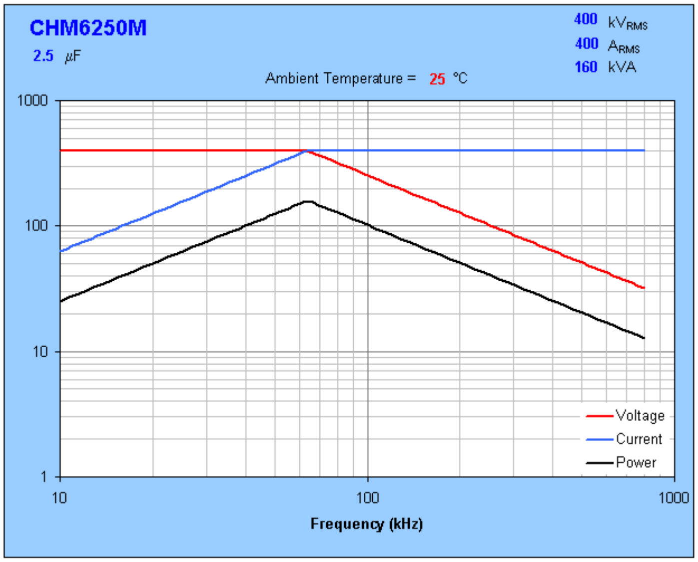




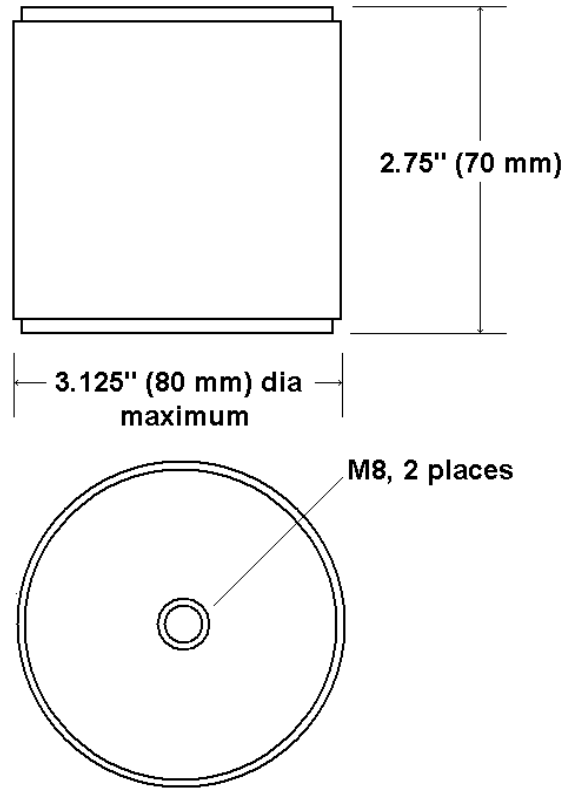








- **Up to 650 V_{RMS} Working Voltage**
- **250 kVA Max Power**
- **Up to 600 A_{RMS} Max Current**
- **Conduction Cooled**
- **Up to 10 µF**



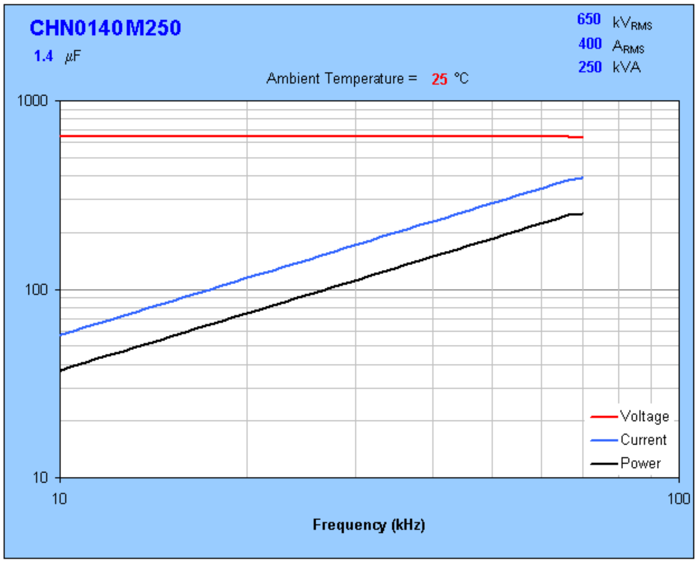
GENERAL SPECIFICATIONS

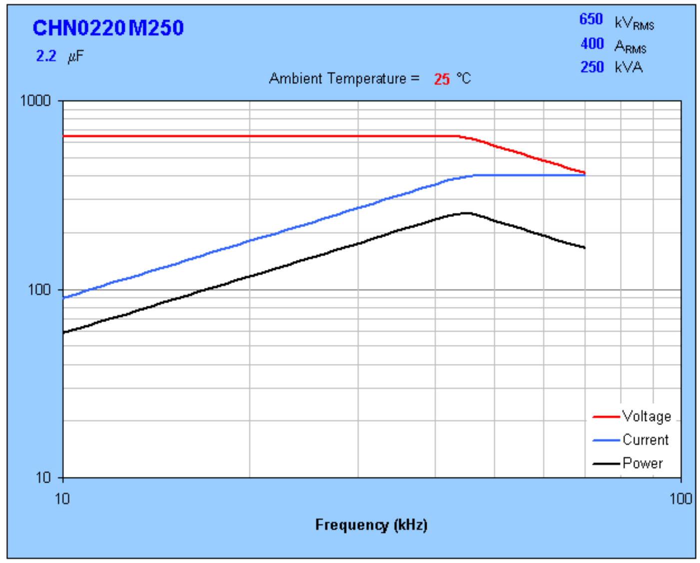
Capacitance Range	1.4 to 10 µF
Capacitance Tolerance	± 10% standard, other tolerances available
Dimensions	80 mm (maximum) diameter x 70 mm high 3 $^{1}/_{8}$ (maximum) diameter x 2 $^{3}/_{4}$ high
Weight	.75 kg; 1.7 lb
Operating Temperature	Up to +90° C
Cooling method	Conduction-cooled by bus bars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

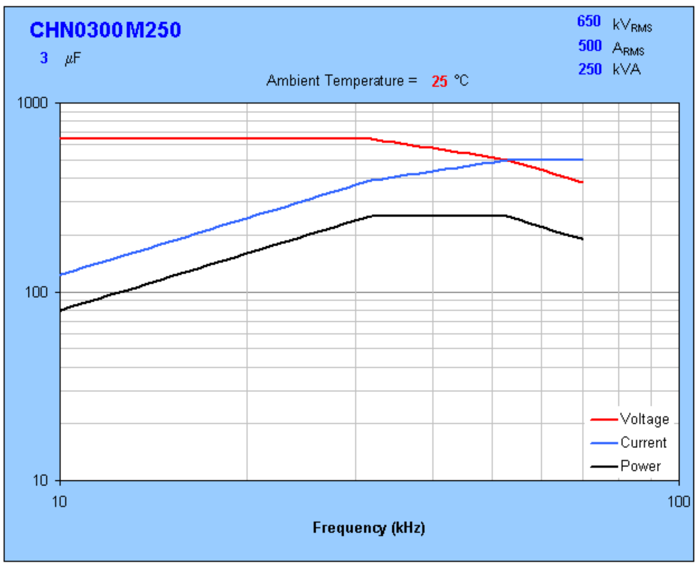
CAP (µF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	PART NUMBER
1.4	**650**	67	**250**	73	**400**	**70**	CHN0140M250
2.2	**650**	43	**250**	46	**400**	**70**	CHN0220M250
3.0	**650**	31	**250**	53	**500**	**70**	CHN0300M250
6.2	**600**	18	**250**	37	**600**	**70**	CHN0620M250
8.5	**600**	13	**250**	27	**600**	**70**	CHN0850M250
10	**600**	11	**250**	23	**600**	**70**	CHN1000M250

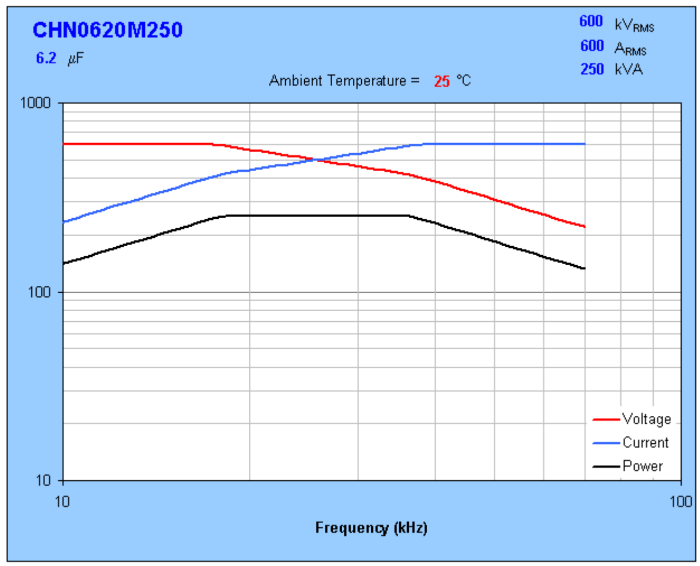
Custom capacitance values are available upon request.

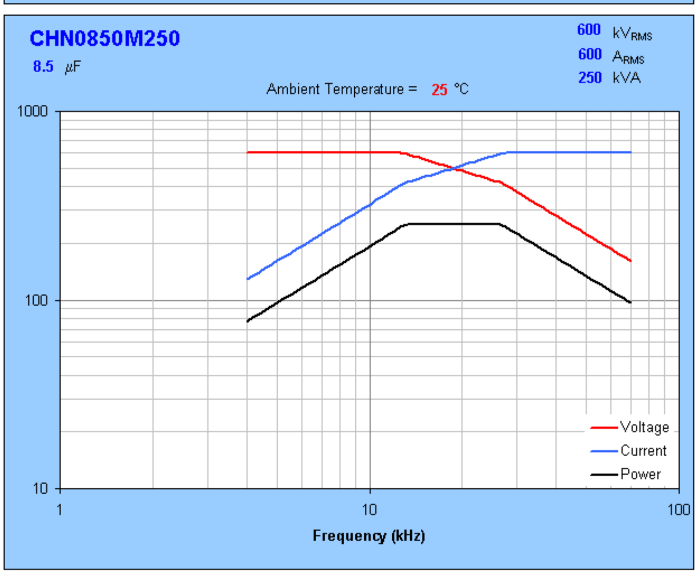
Typical Maximum Rating Curves for CHN0 Series Capacitors

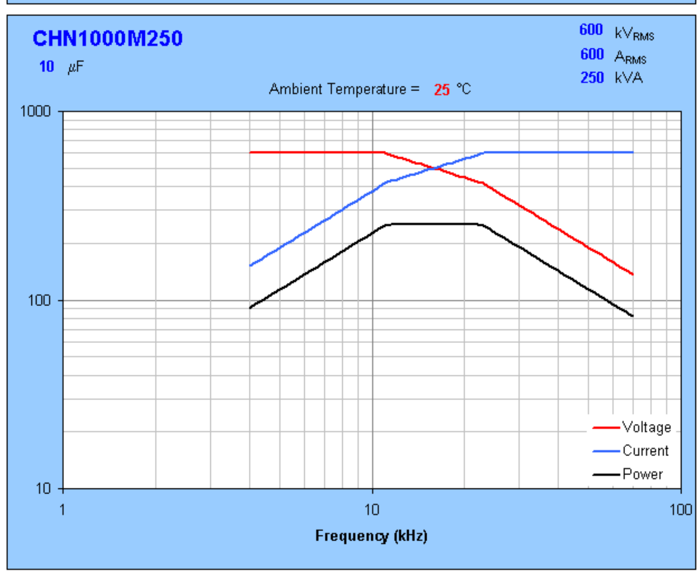




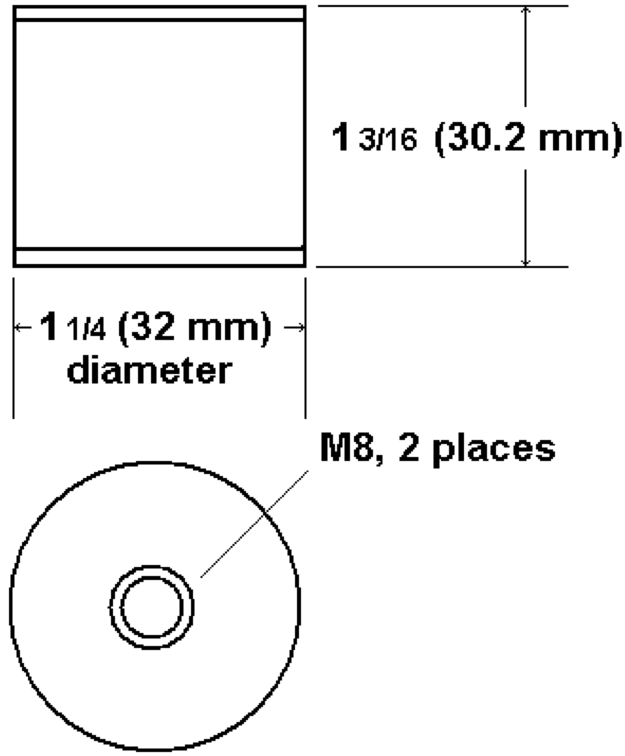








- **Up to 1000 V_{RMS} Working Voltage**
- **120 kVA Max Power**
- **Up to 125 A_{RMS} Max Current**
- **Conduction Cooled**



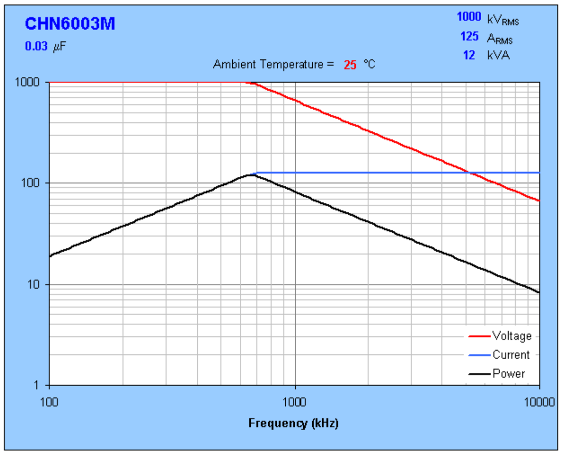
GENERAL SPECIFICATIONS

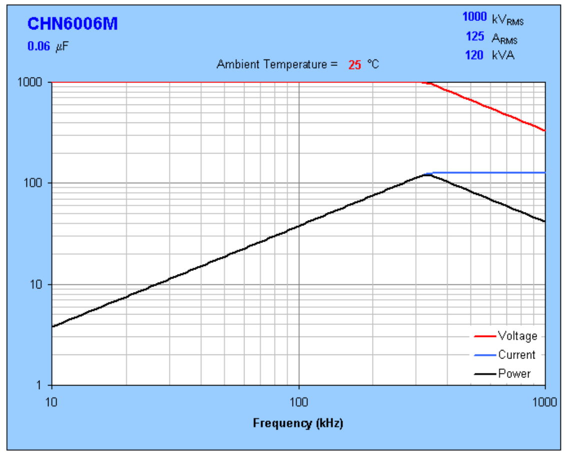
Capacitance Range	0.025 to 1.2 μF
Capacitance Tolerance	± 10% standard, other tolerances available
Dimensions	30 mm diameter x 29 mm high 1 $^{3}/_{16}$“ diameter x 1 $^{1}/_{8}$“ high
Weight	.15 kg; .33 lb
Operating Temperature	Up to +90° C
Cooling method	Conduction-cooled by bus bars
Dissipation Factor	0.1% Maximum
Stray Inductance	less than 5 nH

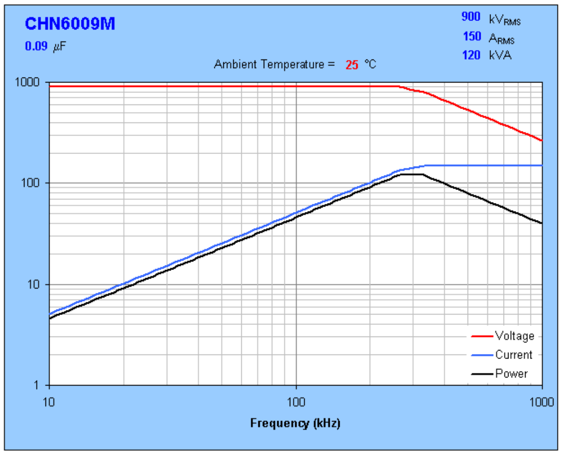
CAP (μF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	PART NUMBER
0.03	**1000**	636	**120**	690	**125**	**10000**	CHN6003M
0.06	**1000**	318	**120**	345	**125**	**1000**	CHN6006M
0.09	**900**	262	**120**	331	**150**	**1000**	CHN6009M
0.17	**800**	175	**120**	175	**150**	**1000**	CHN6017M
0.25	**800**	119	**120**	162	**175**	**1000**	CHN6025M
0.33	**700**	118	**120**	161	**200**	**1000**	CHN6033M
0.66	**600**	80	**120**	102	**225**	**1000**	CHN6066M
1.2	**450**	79	**120**	83	**275**	**1000**	CHN6120M

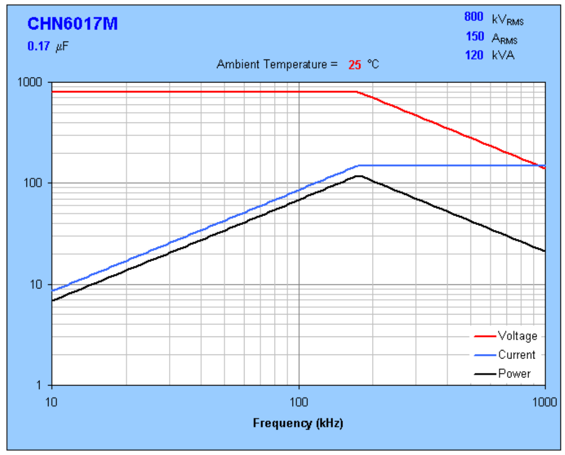
Custom capacitance values are available upon request.

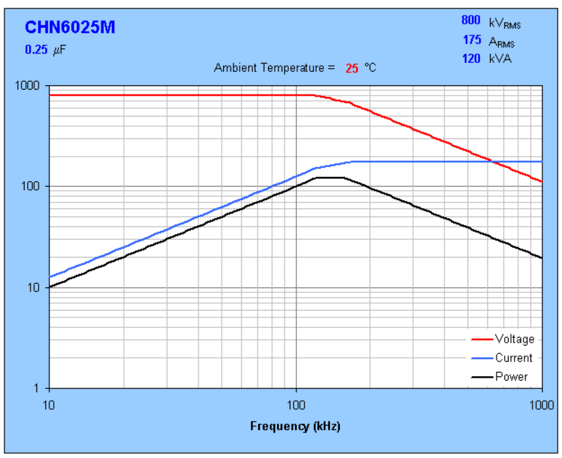
Typical Maximum Rating Curves for CHN6 Series Capacitors

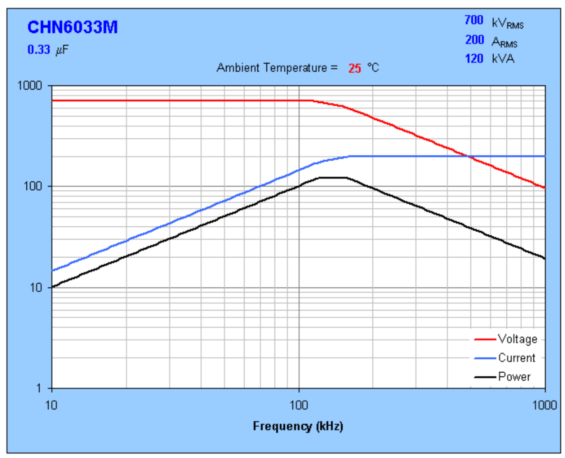


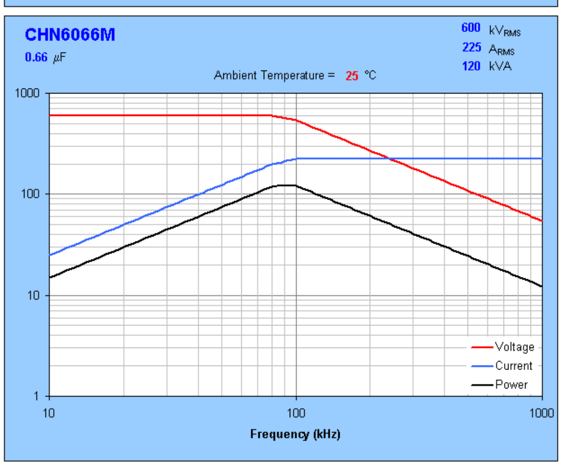


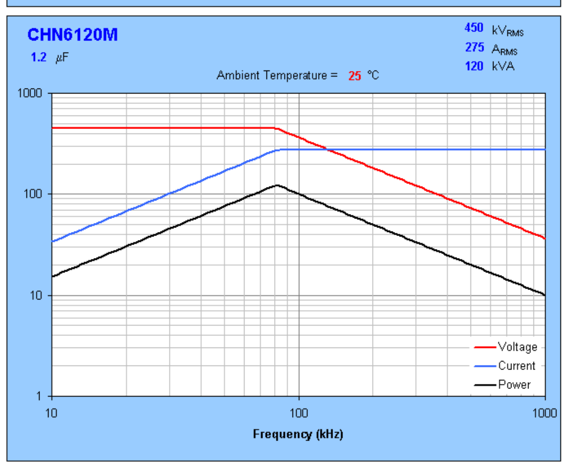




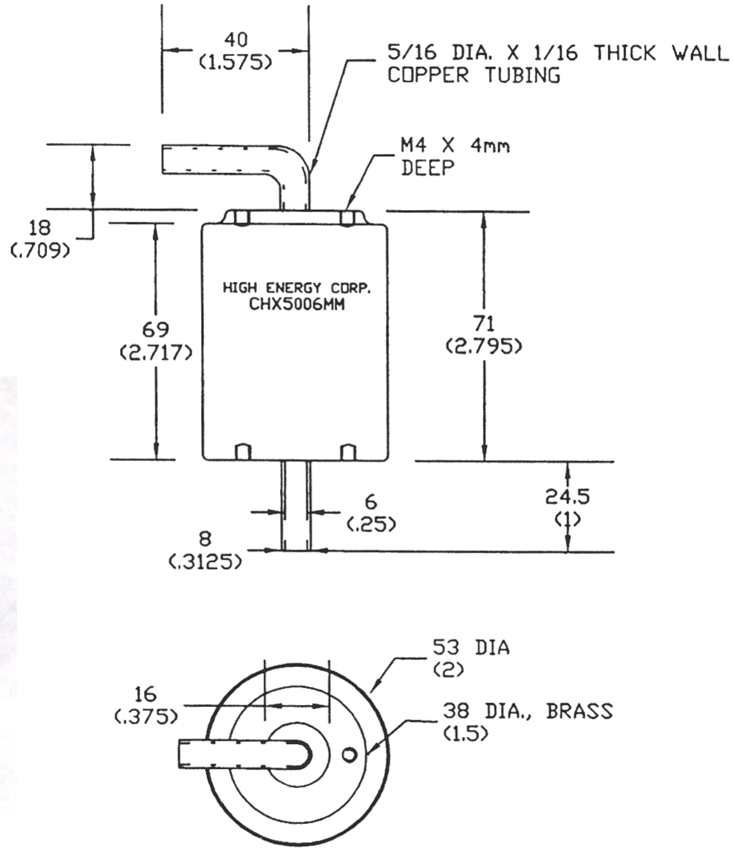








- **1500 V_{RMS} Working Voltage**
- **300 kVA Max Power**
- **Up to 200 A_{RMS} Max Current**
- **Water-Cooled**

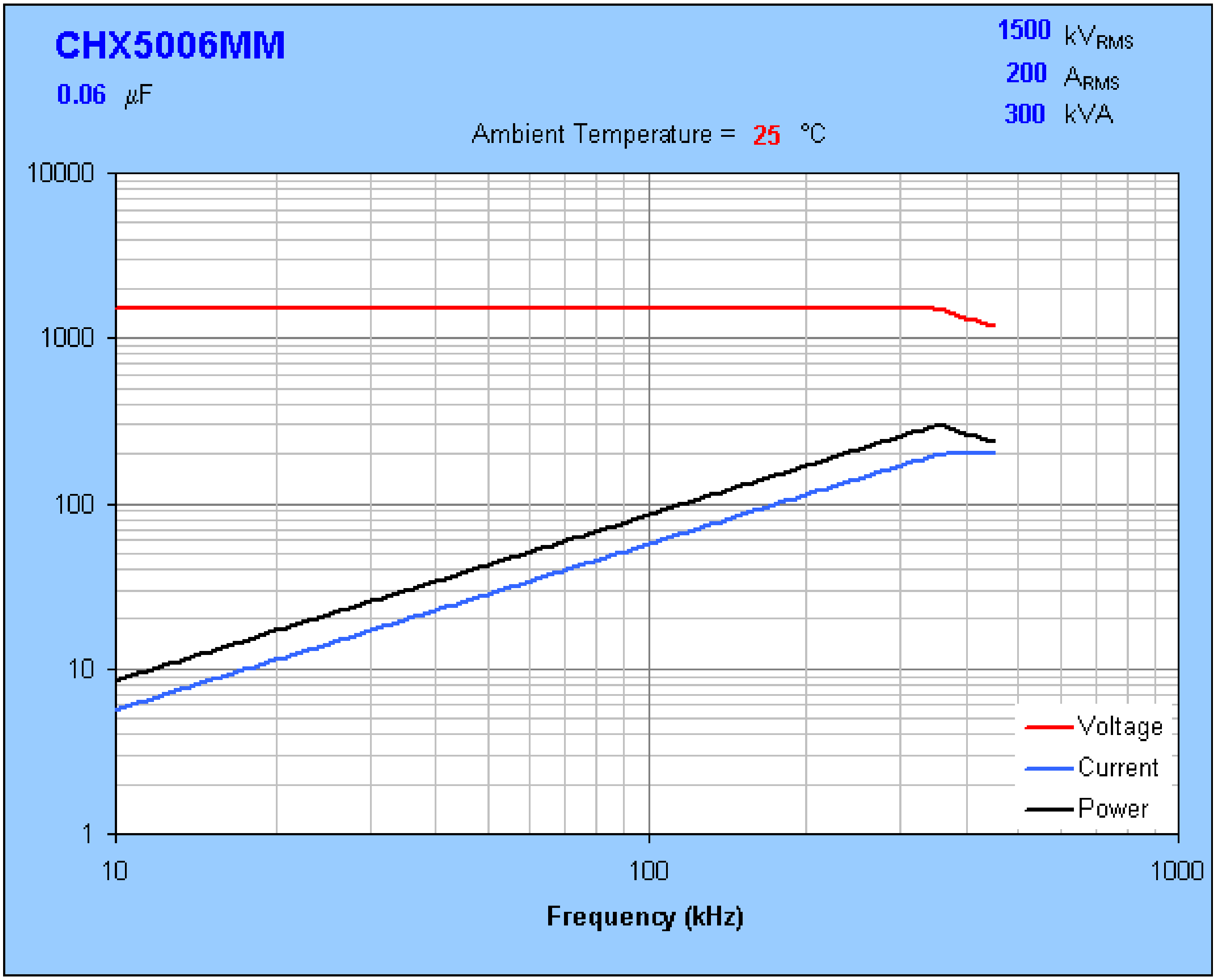


GENERAL SPECIFICATIONS

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

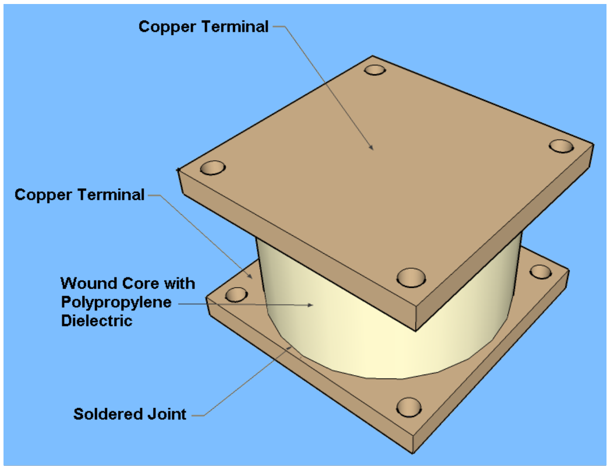
CAP (µF)	V_{MAX} (V_{RMS})	f_L (kHz)	S_{MAX} (kVA)	f_H (kHz)	I_{MAX} (A_{RMS})	f_{MAX} (kHz)	PART NUMBER
0.06	**1500**	353	**300**	353	**200**	**450**	CHX5006MM
<0.06	Custom						CHX500xMx
>0.06	Custom						CHX50xxMx

* 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:

$$C = \frac{KA\varepsilon_0}{t} \qquad (1)$$

C = Capacitance in *Farads* (F)
K = Relative Dielectric Constant (dimensionless)
A = Surface area of each electrode (m^2)
$\boldsymbol{\varepsilon_0}$ = Permittivity of vacuum = 8.854×10^{-12} (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.

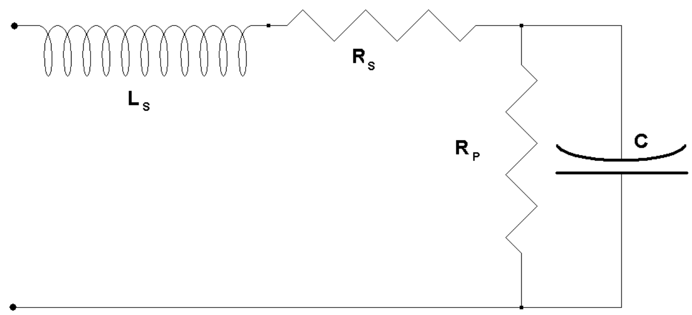
Basic Electronic Considerations

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

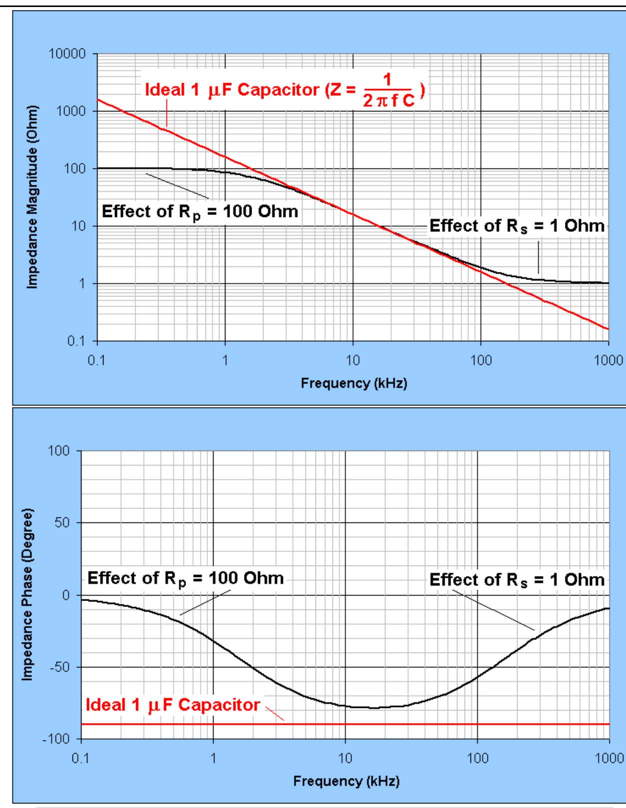
$$Z(f) = \frac{V(f)}{i(f)} = \frac{1}{2\pi fC}\langle -90^{\circ} \qquad (2)$$

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

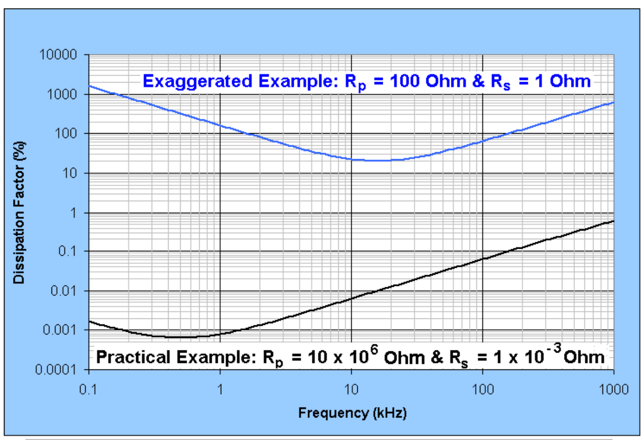


Effect of (exaggerated) R_p and R_s on impedance.

As shown (by the red traces) in the directly preceding figure, the *magnitude* of a (1 μF) 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, $\mathbf{R_p}$ and $\mathbf{R_s}$.

A low value of parallel or 'leakage' resistor, $\mathbf{R_p}$, causes a *reduction* of the capacitor's impedance at frequencies less than $\mathbf{1/2\pi R_pC}$ Hz. It also causes the *phase* to deviate from -90° towards 0°. A high value of series resistor, $\mathbf{R_s}$, causes an *increase* in capacitor impedance for frequencies above $\mathbf{1/2\pi R_sC}$ with a phase shift towards 0°.

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



Dissipation Factors comparing effect of $\mathbf{R_p}$ and $\mathbf{R_s}$.

The *Dissipation Factor* (DF), δ, 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.

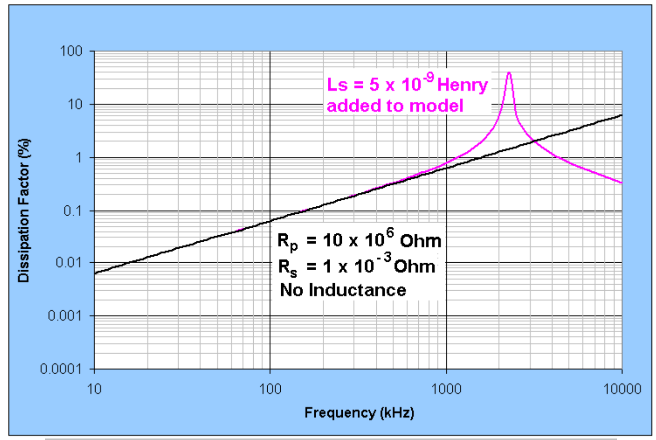
The Dissipation Factor is thus also equal to the ratio of (heat producing) *real power* dissipated within the capacitor to the *reactive power* oscillating through it. Note that for an 'ideal' capacitor (prior red traces) the Dissipation Factor is zero-valued at all frequencies and cannot be plotted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

Now consider the influence of a "series inductance", $\mathbf{L_s}$:

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*, $\mathbf{f_n}$, defined by:

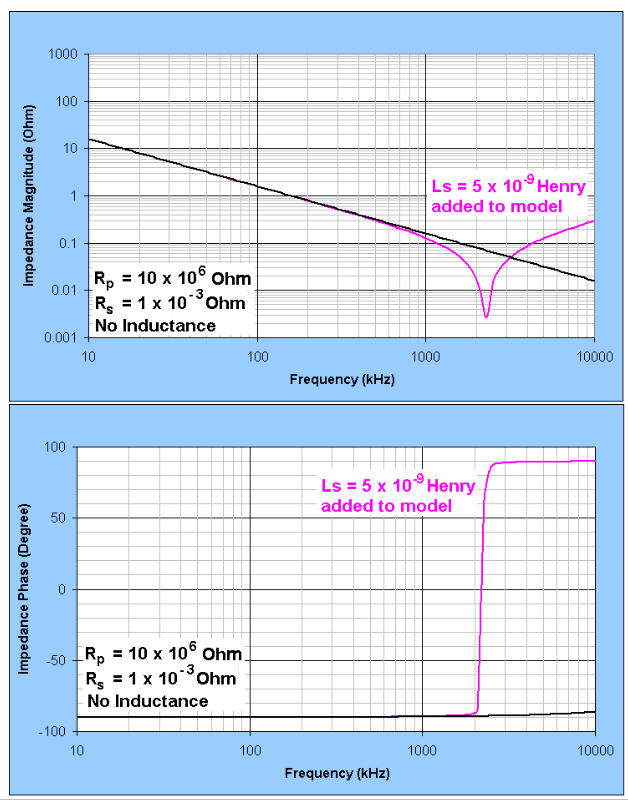
$$f_n = \frac{1}{2\pi}\sqrt{\frac{1}{LC}} \text{ (Hz)} \tag{3}$$

Note changed frequency axis to accentuate the effects of L_s.



Dissipation Factor for realistic parameter values.

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 $\mathbf{f_n}$, as shown below.

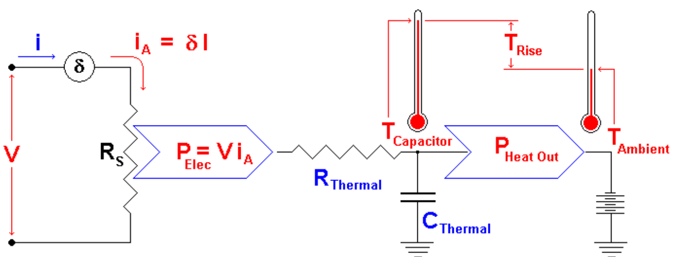


Impedance *Magnitude* and *Phase* with and without $\mathbf{L_s}$.

Performance Limits & Thermodynamics

The *Leakage Resistance*, $\mathbf{R_p}$, is fundamentally determined by the *resistivity* of the dielectric and the terminal-to-terminal insulation of the capacitor. The *Equivalent Series Resistance* (ESR), $\mathbf{R_s}$, is dominated by the quality of the soldered joints between the *terminals* and the *electrodes*. The *Equivalent Series Inductance* (ESL), $\mathbf{L_s}$, 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.



Thermal model of a capacitor in its environment.

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 <u>not</u> in perfect phase-quadrature. The total current contains a small (-60 dB, typical) *active* component, $\mathbf{I_A}$, in phase-coincidence with the voltage. The product (of RMS values), $\mathbf{V \cdot I_A = P}$, defines the *active* electrical power (Watts) dissipated within the capacitor as heat. $\mathbf{I_A}$ is well approximated by $\mathbf{I \cdot \delta}$, where δ is the previously defined dissipation factor.

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

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

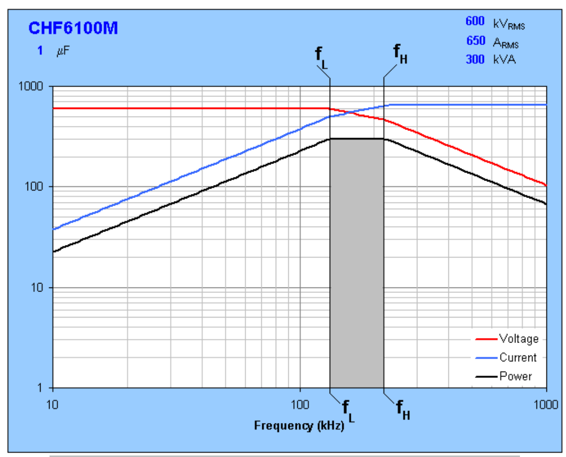
When the capacitor is at the *same* temperature ($\mathbf{T_{Ambient}}$) as it surroundings, it cannot expel any heat. As its temperature increases (by $\mathbf{T_{Rise}}$) above the surrounding $\mathbf{T_{Ambient}}$, it is able to pass thermal power, $\mathbf{P_{Heat\ Out}}$, to the environment.

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

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

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

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



Maximum Rating curves for a capacitor.

Within that frequency band bounded by lower frequency, $\mathbf{f_L}$, and upper frequency, $\mathbf{f_U}$, the *limiting specification* is the maximum rated apparent power. $\mathbf{S_{max}}$ 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 <u>voltage and current must be less than their respective maximum ratings</u>.

Below $\mathbf{f_L}$, the limiting specification is the maximum rated voltage, $\mathbf{V_{Max}}$. In this region, both the current and power must be less than their maximum rated values. Above $\mathbf{f_U}$, the limiting specification is the maximum rated current, $\mathbf{I_{Max}}$. In this frequency span, both the voltage and power must be less than their maximum rated values.

Published specifications for High Energy metallized film capacitors reflect design calculations and experimental verification. Each rating incorporates an appropriate *Safety Factor*, assuring a long-lived component if operated within the ratings.

The maximum rated voltage, V_{Max}, is the root-mean square (RMS) measurement of the voltage applied across the terminals of the part

The maximum rated current, I_{Max}, is the root-mean-square (RMS) value of the total or *apparent current* flowing through the capacitor.

The maximum rated apparent power, S_{Max}, is the product of the RMS voltage applied to the capacitor and the RMS current flowing through it (without regard to phase). This measurement reflects both the dominant *reactive power* and the far smaller heat-producing *active power*.

The apparent power, **S**, at any frequency, **f**, is related to the root-mean-square current, $\mathbf{I_{RMS}}$ by:

$$S = I_{RMS}^2 \cdot |Z| = \frac{I_{RMS}^2}{2 \cdot \pi \cdot f \cdot C} \le S_{Max} \qquad (5)$$

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

$$f_U = \frac{I_{Max}^2}{2 \cdot \pi \cdot C \cdot S_{Max}} \cong \frac{0.159 \cdot I_{Max}^2}{C \cdot S_{Max}} \qquad (6)$$

The apparent power, **S**, may also be expressed in terms of the voltage across the capacitor, $\mathbf{V_{RMS}}$.

$$S = \frac{V_{RMS}^2}{|Z|} = 2 \cdot \pi \cdot f \cdot C \cdot V_{RMS}^2 \le S_{Max} \qquad (7)$$

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

$$f_L = \frac{S_{Max}}{2 \cdot \pi \cdot C \cdot V_{Max}^2} \cong \frac{0.159 \cdot S_{Max}}{C \cdot V_{Max}^2} \qquad (8)$$

Thus the maximum rated RMS operating voltage may be stated:

$$\begin{aligned} \underset{f<f_l}{V_{RMS}} &= V_{Max} \\ \underset{f_L \le f \le f_U}{V_{RMS}} &= \sqrt{\frac{S_{Max}}{2 \cdot \pi \cdot f \cdot C}} \\ \underset{f>f_U}{V_{RMS}} &= \frac{I_{Max}}{2 \cdot \pi \cdot C \cdot f} \end{aligned} \qquad (9)$$

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

$$\begin{aligned} \underset{f<f_L}{I_{RMS}} &= 2 \cdot \pi \cdot f \cdot C \cdot V_{Max} \\ \underset{f_L \le f \le f_U}{I_{RMS}} &= \sqrt{2 \cdot \pi \cdot f \cdot C \cdot S_{Max}} \\ \underset{f>f_U}{I_{RMS}} &= I_{Max} \end{aligned} \qquad (10)$$

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, $\mathbf{c_p}$, of water is 1 *calorie/gram °C* or 4186 *J/ kg °C*. Multiplying this by water's density, ρ, (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 $\mathbf{\rho c_p}$ to be power per volume-flow x temperature. Thus we can write (11).

$$\frac{P}{F \cdot \Delta T} = \rho C_p = 4186 \qquad (11)$$

Where **P** = heat power entering water (Watt)
F = flow rate of water (liter/second)
ΔT = temperature rise of the water (°C)

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

$$F = \frac{P}{4186 \cdot \Delta T} = \frac{\delta \cdot 1000 \cdot S_{Max}}{4186 \cdot \Delta T} \qquad (12)$$

$$= \frac{.001 \times 1000 \cdot S_{Max}}{4186 \times 40} = \frac{S_{Max}}{167440}$$

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

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

$$lpm = \frac{S_{Max}}{2791} \qquad (13)$$

For the minimum cooling rate in gallon/minute use:

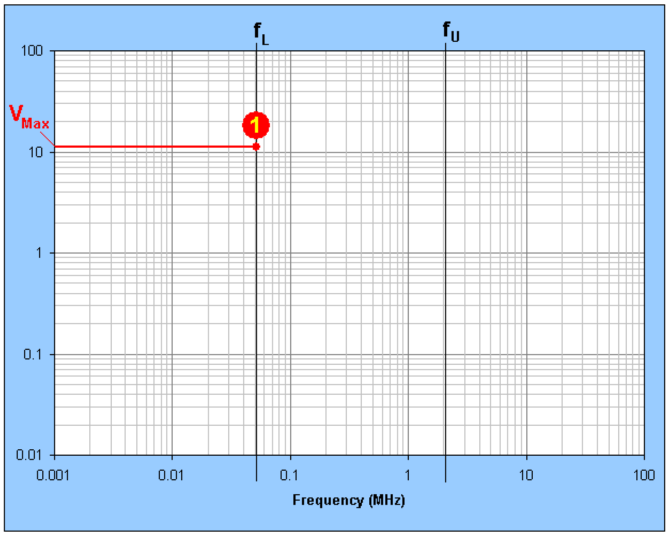
$$gpm = \frac{S_{Max}}{10148} \qquad (14)$$

Plotting Rating Curves for HEC Parts

All parts listed in this catalog are presented with five power parameters: V_{Max}, f_L S_{Max}, F_U and I_{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.

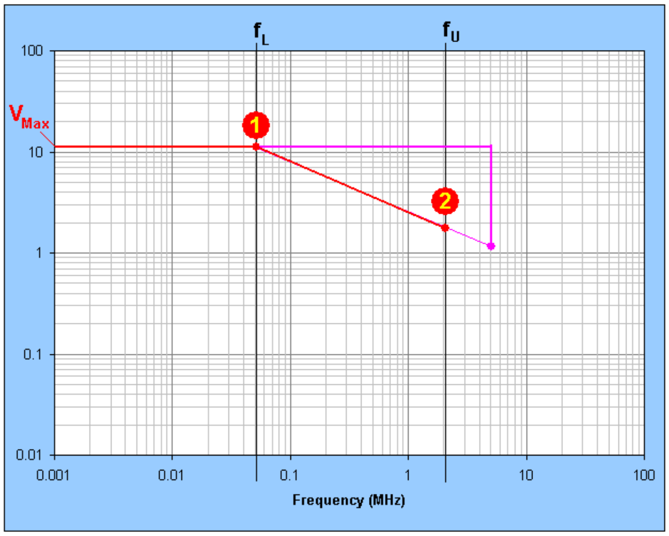
Begin by striking vertical reference lines at the $\mathbf{f_L}$ and $\mathbf{f_U}$ frequency locations as shown above right.

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



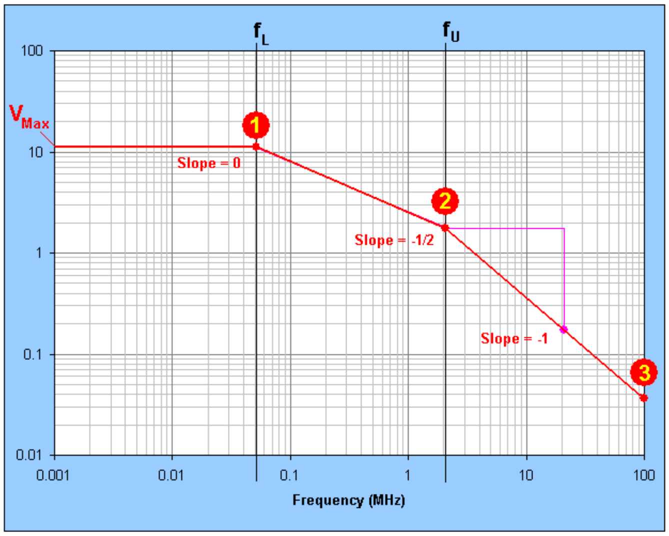
Drawing the vertical and horizontal lines of a V_{Max} plot.

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 $\mathbf{f_U}$.



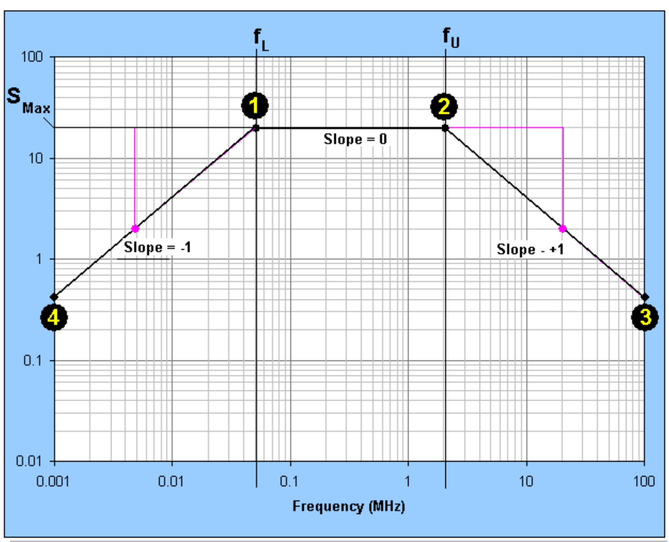
Adding a segment with a slope equal to **–1/2** to the plot.

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.



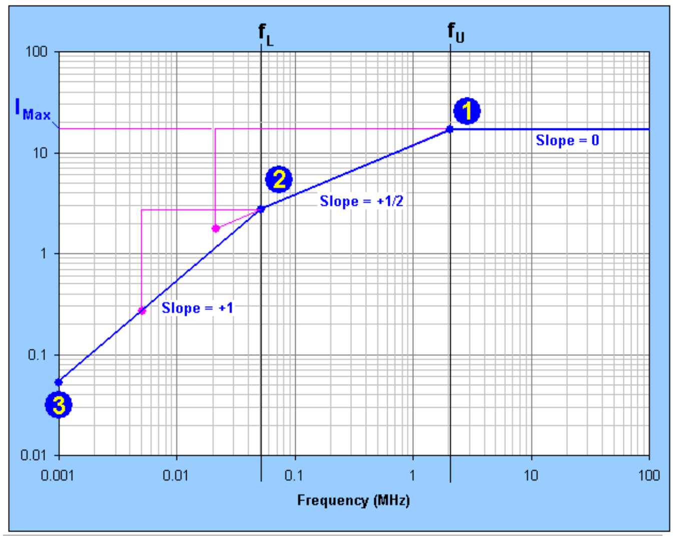
Completing the V_{Max} plot with a segment with a **–1** slope.

To construct a *Maximum Power* diagram, draw a horizontal line at $\mathbf{S_{Max}}$ 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.

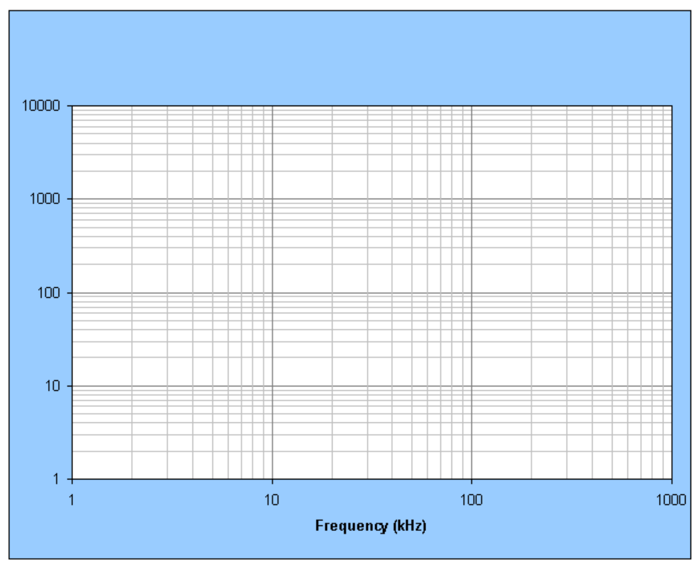


An S_{Max} power plot is drawn with slopes of **–1**, **0** and **+1**.

Finally, draw a *Maximum Current* spectrum by drawing a horizontal line at amplitude $\mathbf{I_{max}}$ from the graph's maximum frequency to **Point 1** at $\mathbf{f_U}$. 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 $\mathbf{f_L}$. 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**.



An I_{Max} plot is constructed with slopes of **+1**, **0** and **+1/2**.



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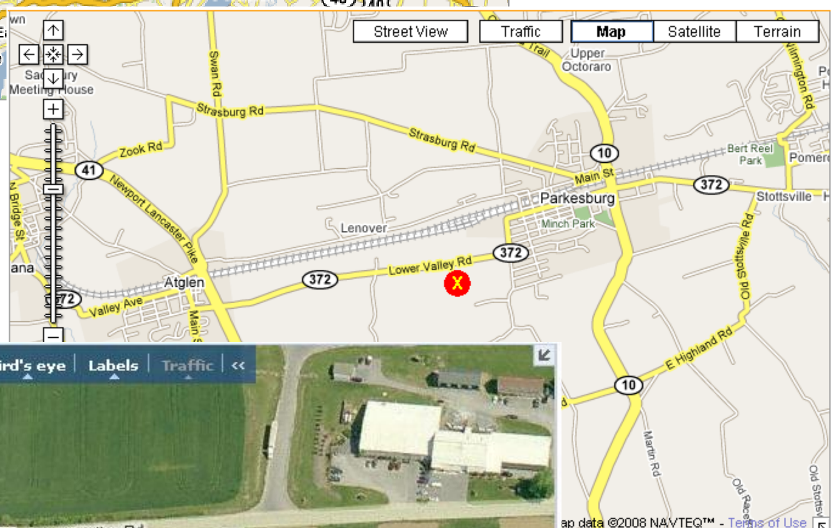

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