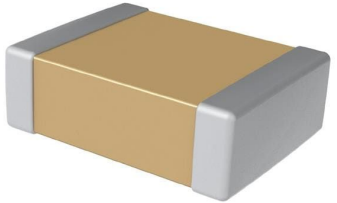
STOP!

(Using the wrong Capacitors)

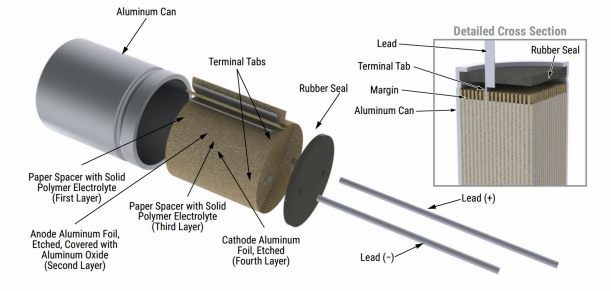
James Lewis
@baldengineer

Agenda

- Capacitor Introduction
- Capacitor Types
  - MLCCs
    - Loss
  - Electrolytics (Al)
    - Operatinal Lifetime
  - Supercapacitor (EDLC)
    - Battery Replacement
  - Film (EMI)
    - The Big No-No.
- Resources
- Q&A

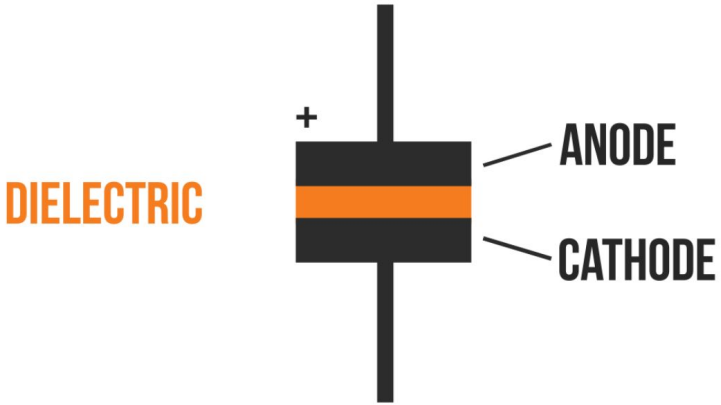


$$C = \frac{k\, e_0\, A}{d}$$

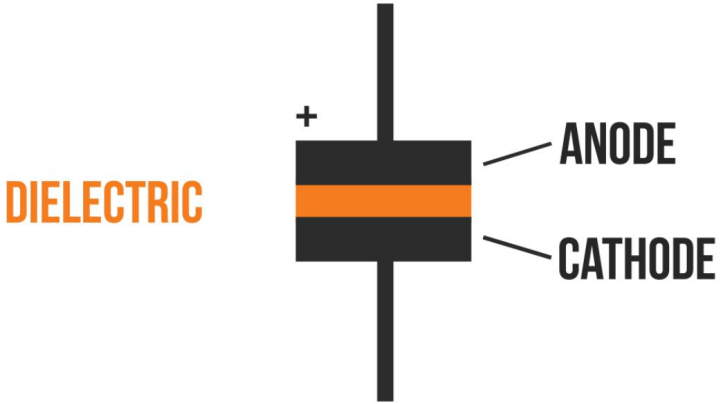


Capacitor Introduction

Capacitor Basics



Capacitor Basics



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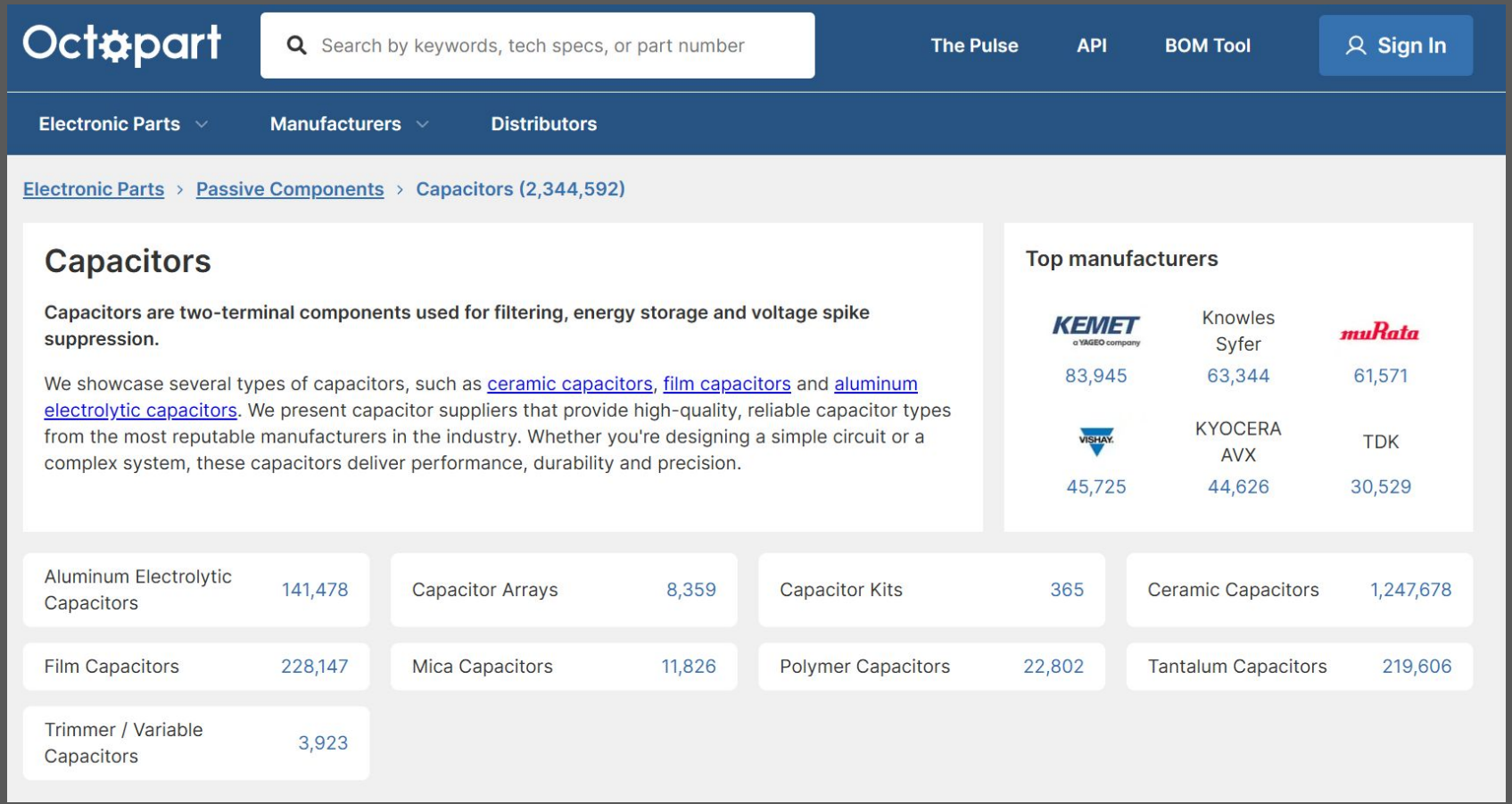

Octopart has 2,344,592 capacitor part numbers

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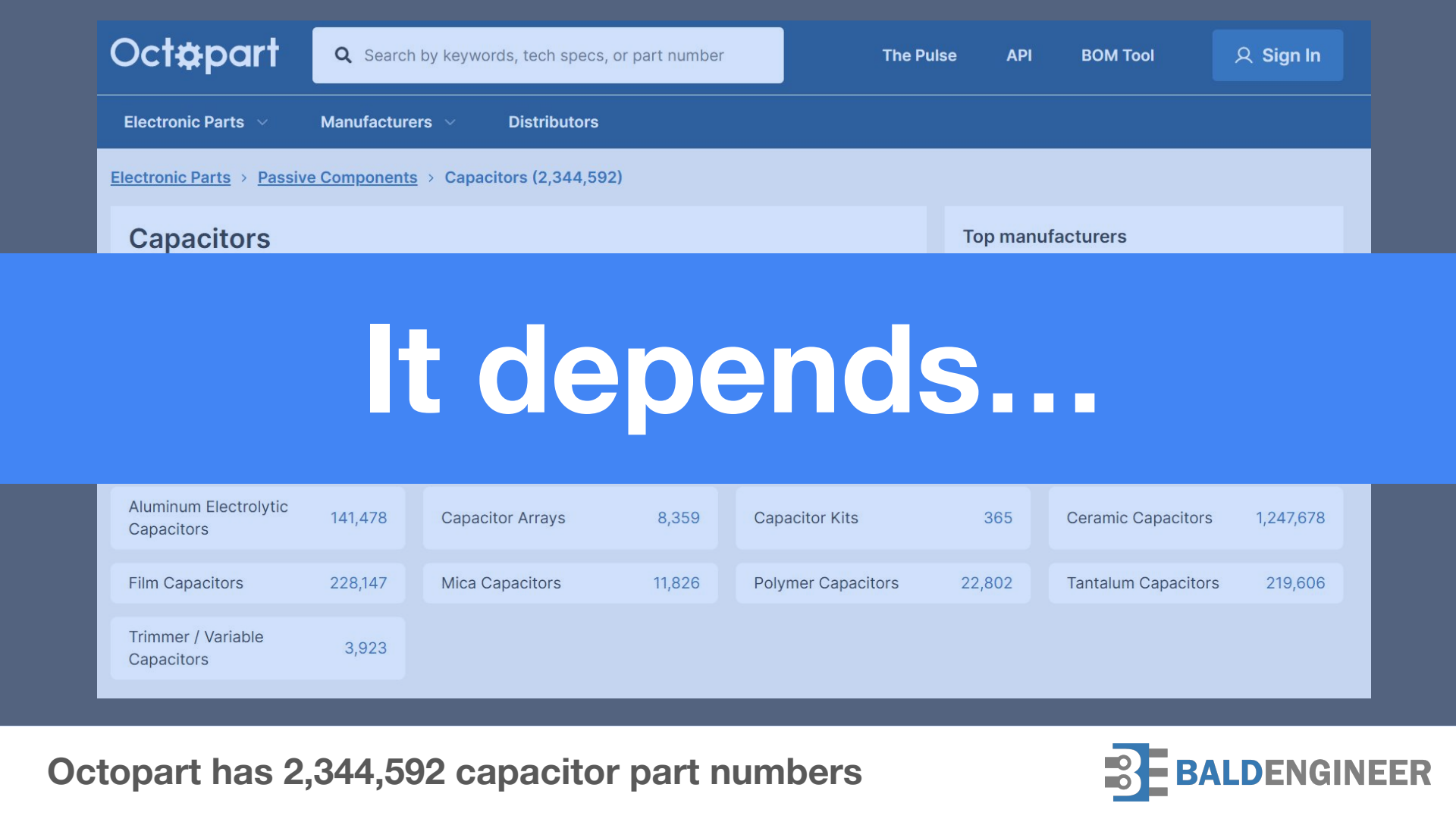

Octopart has 2,344,592 capacitor part numbers

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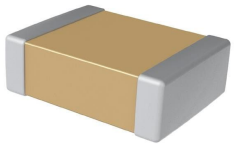
Capacitor Types

Five Major Capacitor Types

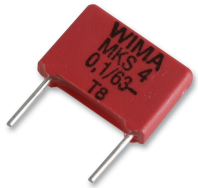
Ceramic



Aluminum Electrolytic

Tantalum

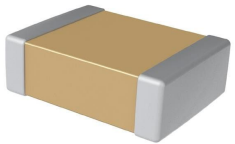
Film



EDLC

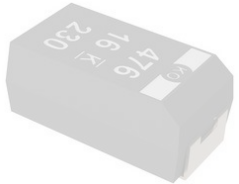
Five Major Capacitor Types

Ceramic

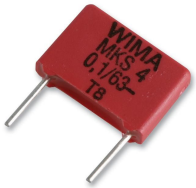


Aluminum Electrolytic

Tantalum



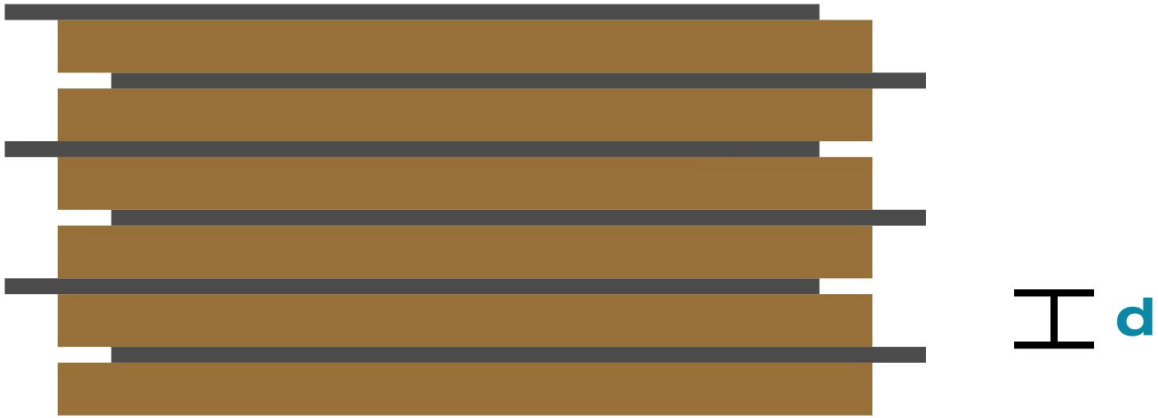
Film



EDLC

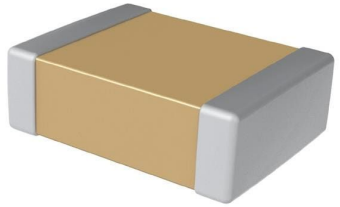
MLCCs

MLCC Structure



$$C = \frac{k\, e_0\, A}{d}$$

Ceramic - 4 Major Losses

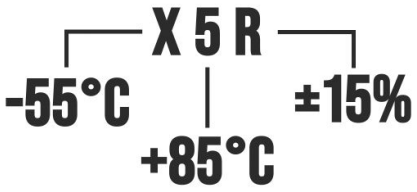


TOLERANCE

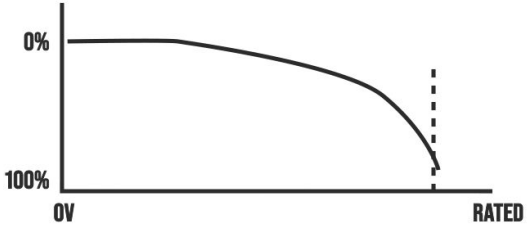
GR	M	18	8	B1	1H	102	K	A01	D
❶	❷	❸	❹	❺	❻	❼	❽	❾	❿

J	±5%
K	±10%
M	±20%

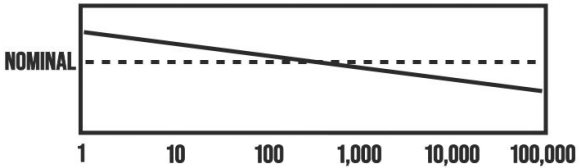
TEMPERATURE



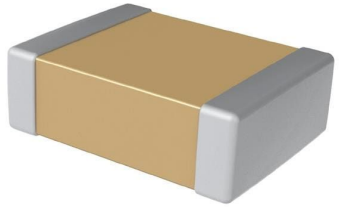
VOLTAGE



AGING



Ceramic - 4 Major Losses



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❶	❷	❸	❹	❺	❻	❼	❽	❾	❿

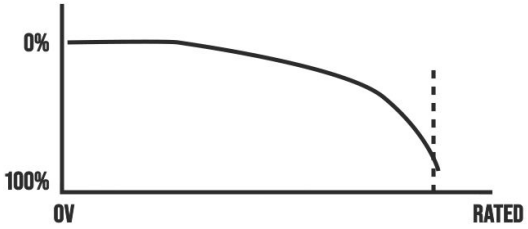
J	±5%
K	±10%
M	±20%

TEMPERATURE

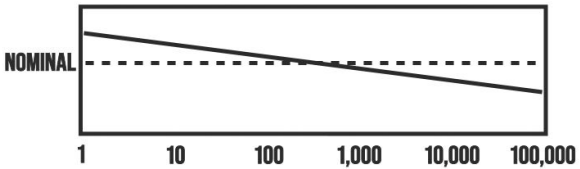
X 5 R

-55°C | +85°C | ±15%

VOLTAGE



AGING




IM3570 IMPEDANCE ANALYZER
MEAS
COMP/BIN
IN
OUT
GUARD
L CUR
UNKNOWN
H POT
H CUR
HIOKI
LCR
Cs
Cp
Z
Ls
8.95883µF
8.92093µF
178.028 Ω
-282.741mH
Vac 999.8mV
Iac 5.616mA
MODE
SET
ADJ
SYS
FILE
INFORMATION
FREQ 100.00 Hz
CV 1.000V
LIMIT OFF
RANGE AUTO 300Ω
LOW Z OFF
JUDGE OFF
SPEED SLOW2
TRIG INT
AVG OFF
DELAY 0.0000s
DCBIAS OFF
OPEN OFF
SHORT OFF
LOAD OFF
CABLE 0m
SCALE OFF
SAVE
ZOOM ON
INFO DC
HIOKI USA Demo Unit
HIOKI
9268-10
DC BIAS VOLTAGE UNIT
MADE IN JAPAN
EXT DC BIAS
±40V
UNKNOWN
H POT
L CUR
H CUR
HIOKI 9263 SMD TEST FIXTURE
LOW
HIGH
±40V DC MAX


IM3570 IMPEDANCE ANALYZER
MEAS
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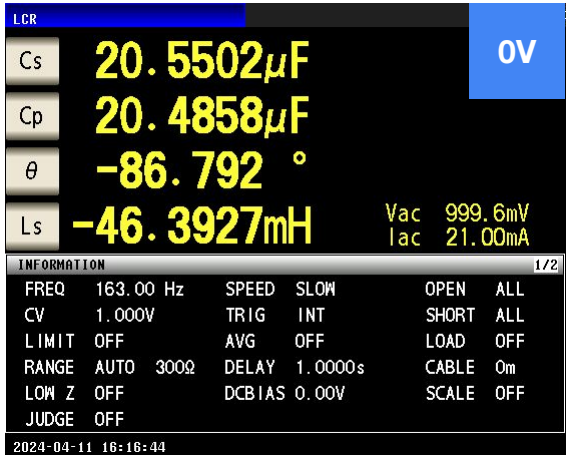
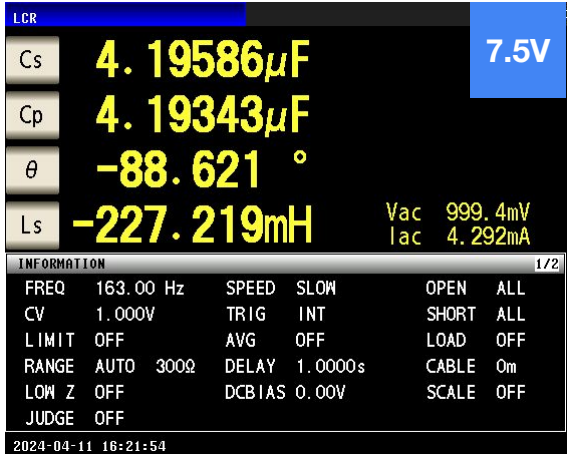
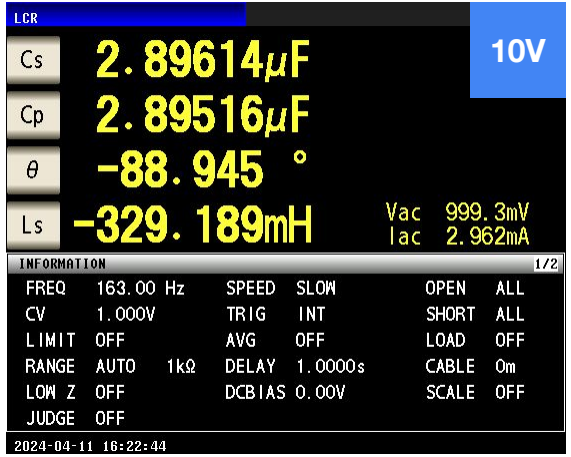
TRIG INT
AVG OFF
DELAY 0.0000s
DCBIAS OFF
OPEN OFF
SHORT OFF
LOAD OFF
CABLE 0m
SCALE OFF
SAVE
ZOOM ON
INFO DC
👉🤣🤷

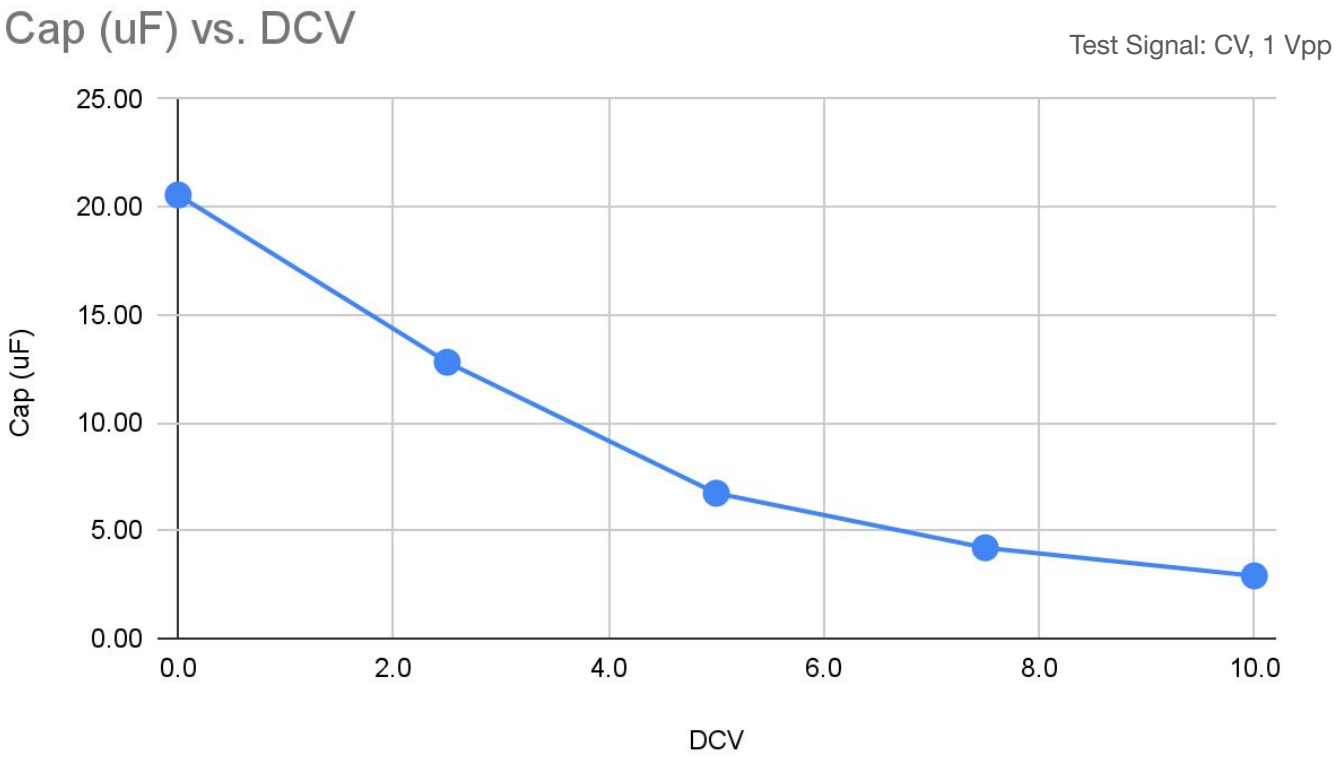
Ceramic DC Bias



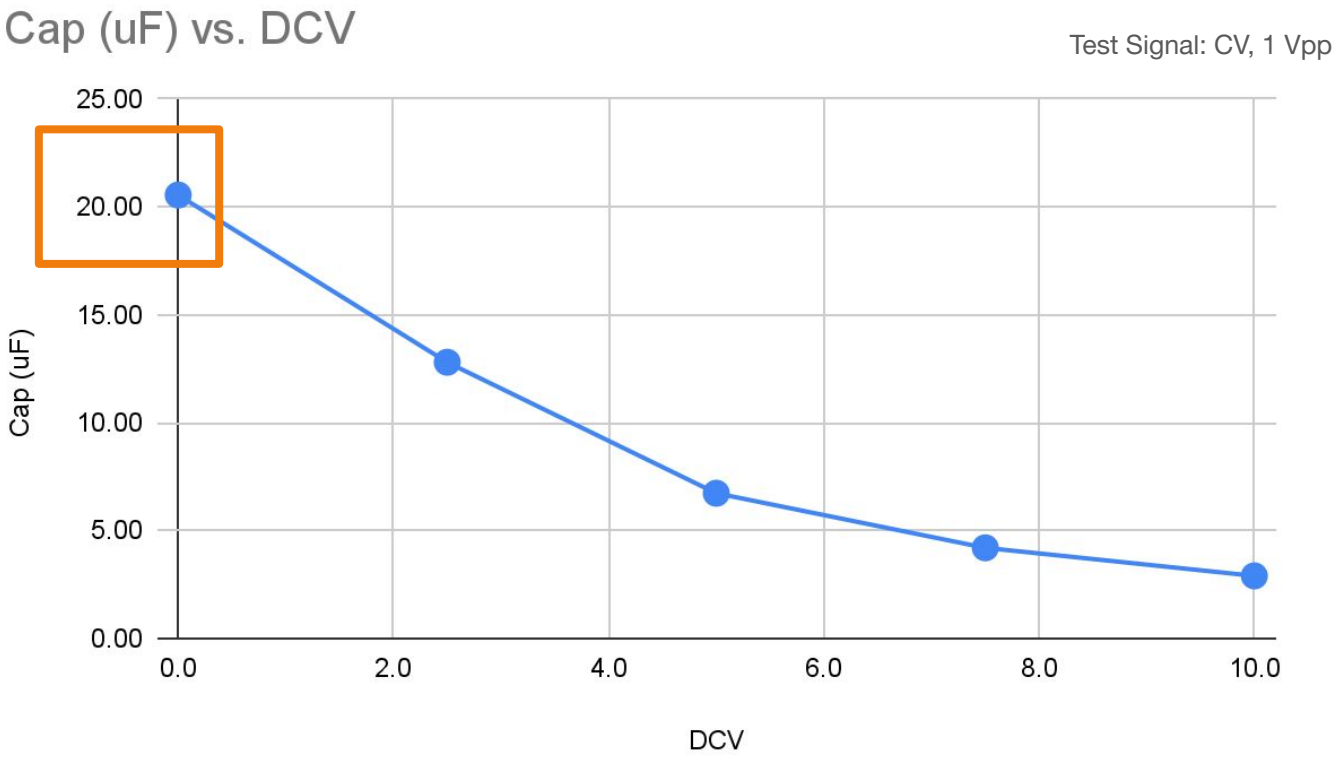




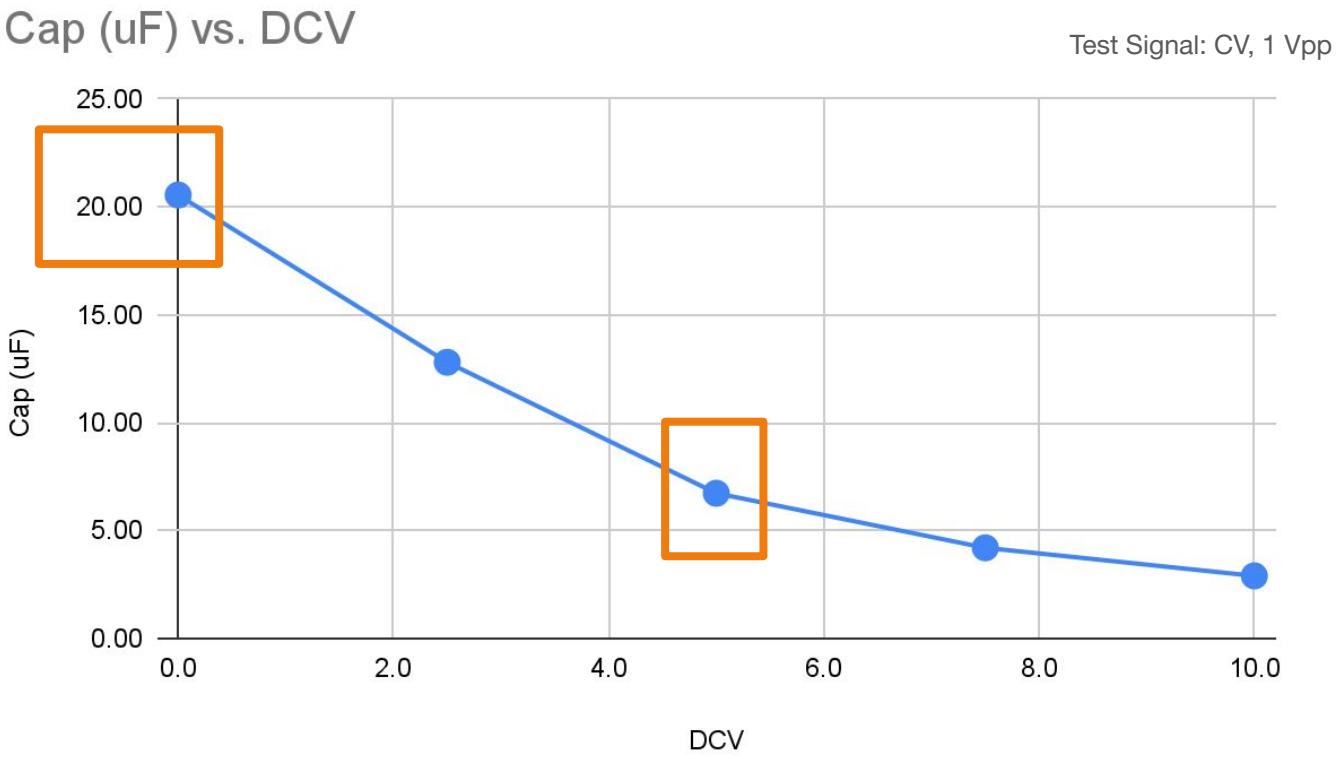
MLCC 22 uF, 10V, 0805, X7R: DC Bias (Graph)



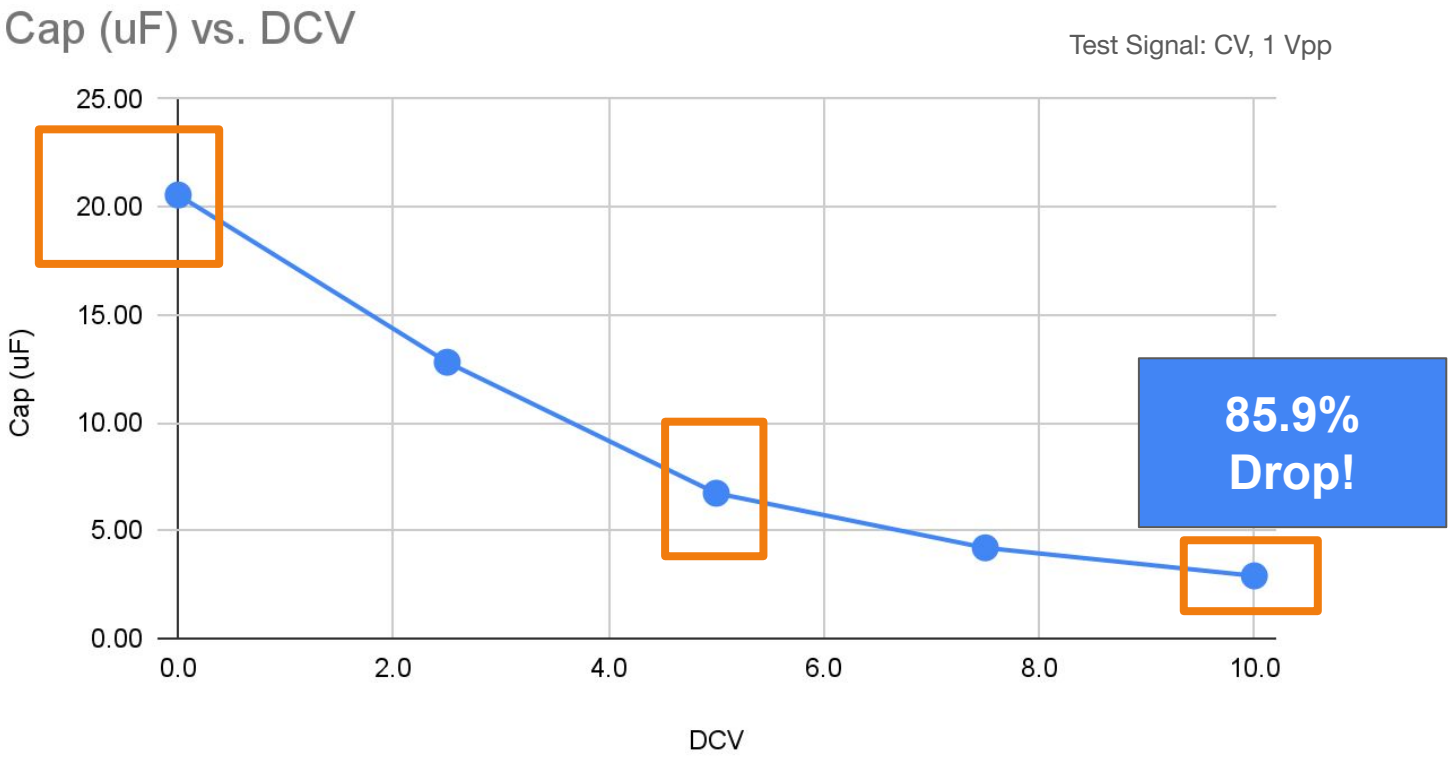
MLCC 22 uF, 10V, 0805, X7R: DC Bias (Graph)



MLCC 22 uF, 10V, 0805, X7R: DC Bias (Graph)



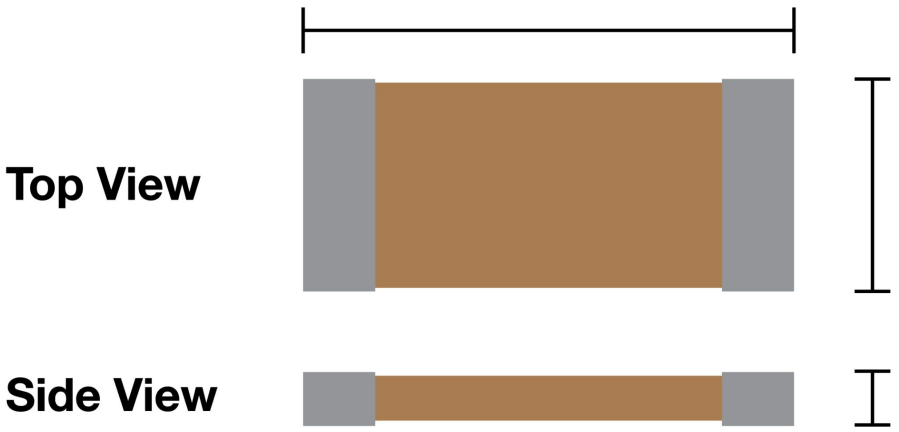
MLCC 22 uF, 10V, 0805, X7R: DC Bias (Graph)



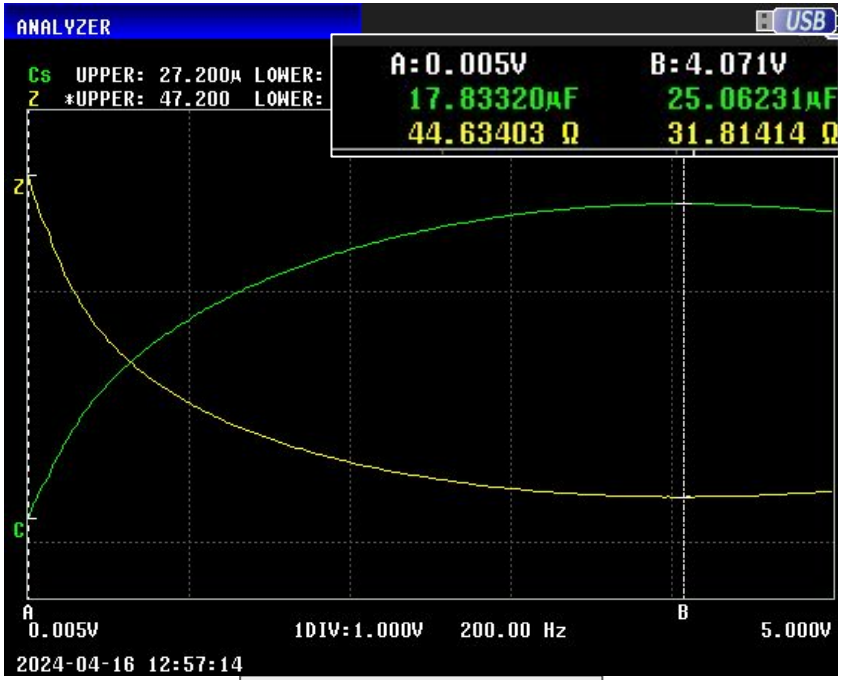
What affects MLCC VCC

Dielectric Thinness (Thickness)

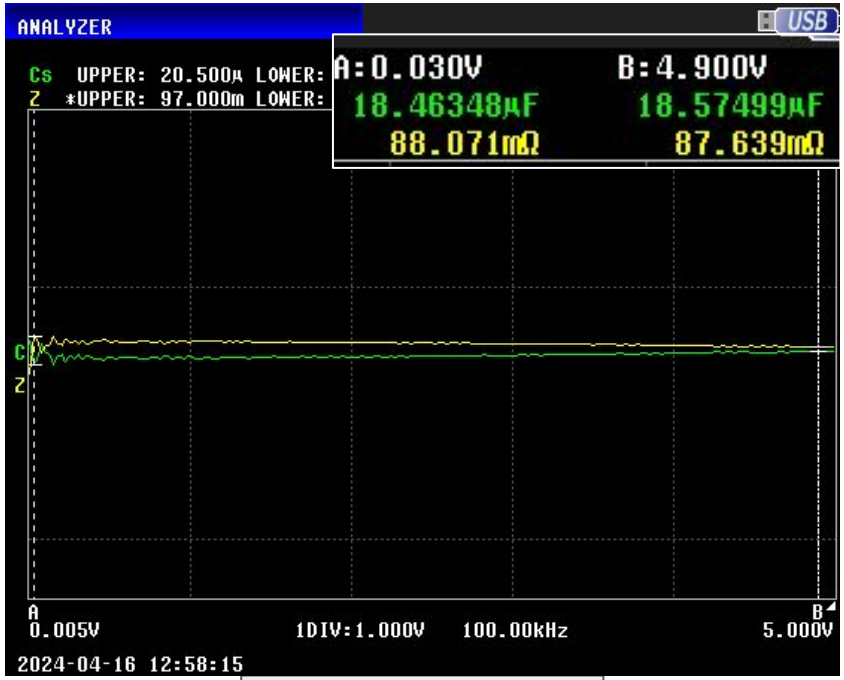
- **Rated Voltage**
  - Lower V = Thinner Dielectric
- **Temperature Coefficient**
  - Less Temp Range = Thinner Dielectric
  - X7R > X5R > Y5V > Z5U
- **Dielectric Surface Area**
  - Smaller X and Y = More Layers
  - Limit is longest side
    - (0805 can't be "taller" than .08)
  - Thinner Layers to get More Layers
    - See Above



MLCC 22 uF, 10V, 0805, X7R AC Signal: Graphs

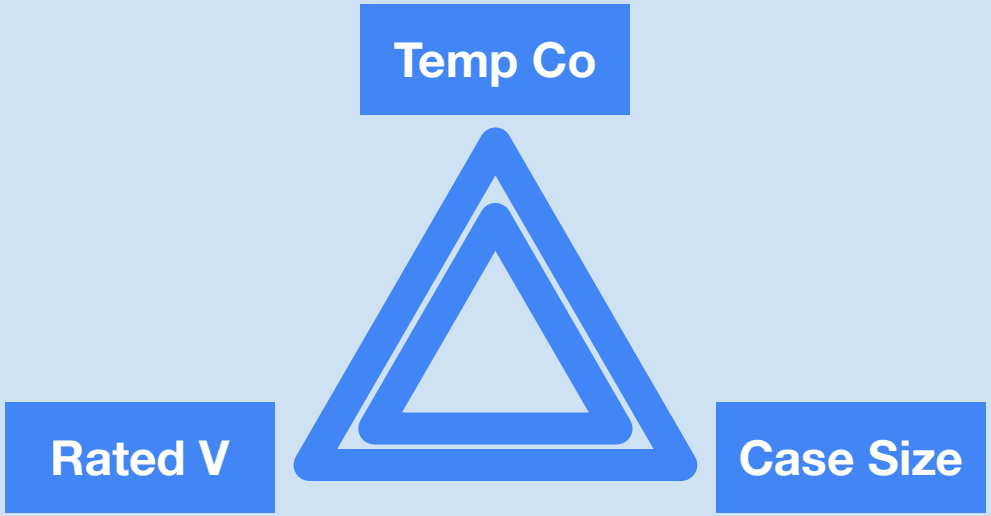


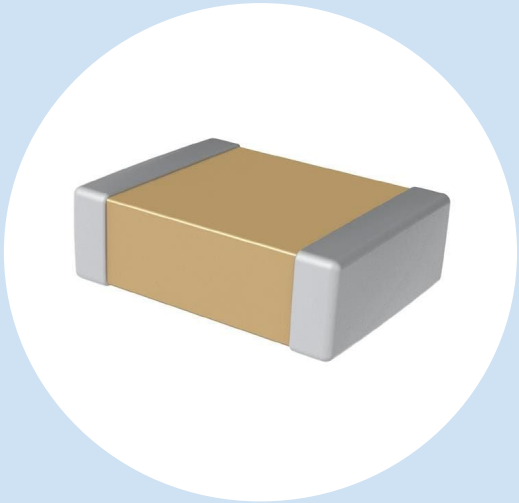
200 Hz
0.005V to 5V



100 kHz
0.030V to 5V

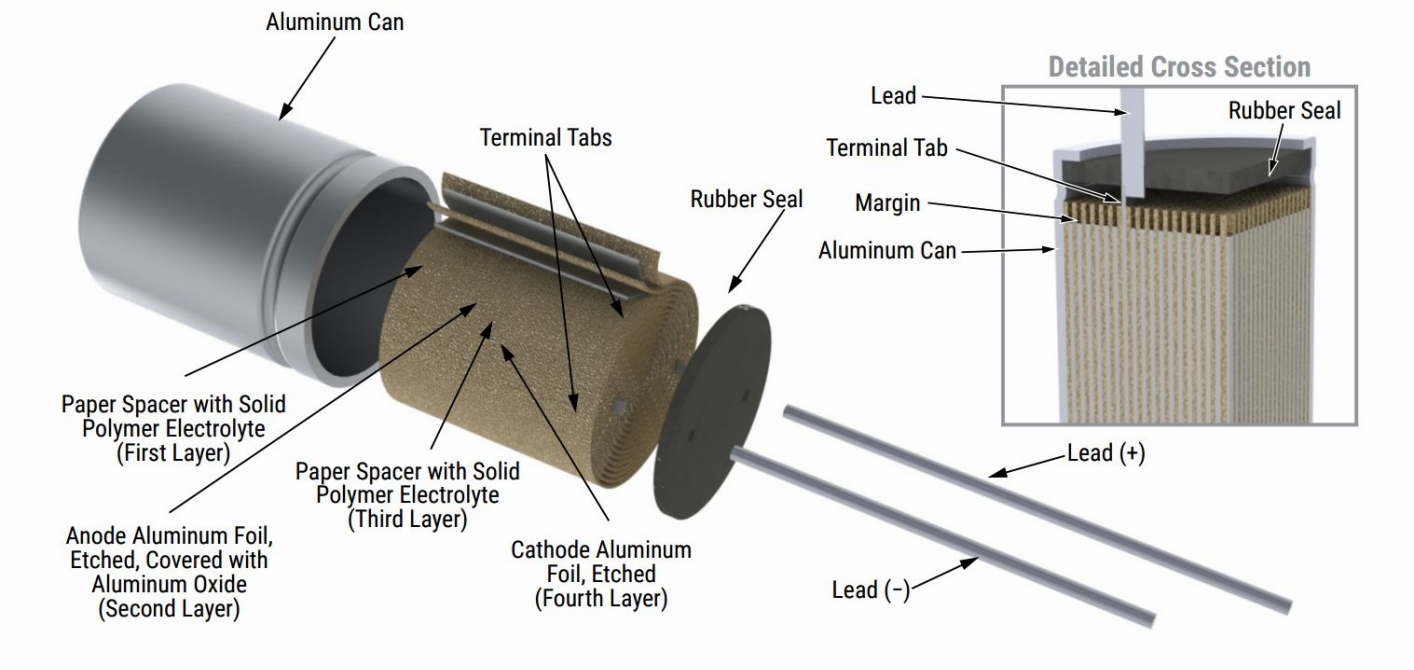
MultiLayer Ceramic Capacitors (MLCCs)





Aluminum Electrolytic

Aluminium Electrolytic



Cross Section from KEMET A750 Series

Traditional Al Electrolytic

Panasonic INDUSTRY

⚠ Some part numbers are discontinued.

Aluminum Electrolytic Capacitors

Radial Lead Type

NHG-A series

■ Not available in Japan

Features

- Endurance : 105 ℃ 1000 h to 2000 h
- AEC-Q200 compliant (6.3 V to 100 V)
- RoHS compliant

Specifications

Category temp. range	–55 ℃ to +105 ℃	–25 ℃ to +105 ℃
Rated voltage range	6.3 V to 100 V	160 V to 450 V
Capacitance range	2.2 μF to 22000 μF	2.2 μF to 330 μF
Capacitance tolerance	±20 % (120 Hz / +20℃)	
Leakage current	I ≦ 0.01 CV or 3 (μA) After 2 minutes (Which is greater)	I ≦ 0.06 CV + 10 (μA) After 2 minutes
Dissipation factor (tan δ)	Please see the attached characteristics list	
Endurance	After following life test with DC voltage and +105 ℃±2 ℃ ripple current value applied (The sum of DC and ripple peak voltage shall not exceed the rated working voltage) for 2000 h, when the capacitors are restored to 20 ℃, the capacitors shall meet the limits specified bellow. Duration 6.3 V to 100 V (ø5 to ø8) : 1000 h, (ø10 to ø18) : 2000 h 160 V to 450 V : 2000 h	
	Capacitance change	Within ±20 % of the initial value
	Dissipation factor (tan δ)	≦ 200 % of the initial limit
	DC leakage current	Within the initial limit
Shelf life	After storage for 1000 h at +105 ℃±2 ℃ with no voltage applied and then being stabilized at +20 ℃, capacitors shall meet the limits specified in endurance. (With voltage treatment)	

Traditional Al Electrolytic

Panasonic
INDUSTRY

⚠ Some part numbers are discontinued.

Aluminum Electrolytic Capacitors

Radial Lead Type

NHG-A series

■ Not available in Japan

- Endurance : 105 ℃ 1000 h to 2000 h
- to 2000 h
- AEC-Q200 compliant (6.3 V to 100 V)
- RoHS compliant

Specifications

Category temp. range	–55 ℃ to +105 ℃	–25 ℃ to +105 ℃
Rated voltage range	6.3 V to 100 V	160 V to 450 V
Capacitance range	2.2 µF to 22000 µF	2.2 µF to 330 µF
Capacitance tolerance	±20 % (120 Hz / +20℃)	
Leakage current	I ≦ 0.01 CV or 3 (µA) After 2 minutes (Which is greater)	I ≦ 0.06 CV + 10 (µA) After 2 minutes
Dissipation factor (tan δ)	Please see the attached characteristics list	
Endurance	After following life test with DC voltage and +105 ℃±2 ℃ ripple current value applied (The sum of DC and ripple peak voltage shall not exceed the rated working voltage) for 2000 h, when the capacitors are restored to 20 ℃, the capacitors shall meet the limits specified bellow. Duration 6.3 V to 100 V (ø5 to ø8) : 1000 h, (ø10 to ø18) : 2000 h 160 V to 450 V : 2000 h	
	Capacitance change	Within ±20 % of the initial value
	Dissipation factor (tan δ)	≦ 200 % of the initial limit
	DC leakage current	Within the initial limit
Shelf life	After storage for 1000 h at +105 ℃±2 ℃ with no voltage applied and then being stabilized at +20 ℃, capacitors shall meet the limits specified in endurance. (With voltage treatment)	

Traditional Al Electrolytic

Panasonic INDUSTRY

⚠ Some part numbers are discontinued.

Aluminum Electrolytic Capacitors

Radial Lead Type

NHG-A series

■ Not available in Japan

- Endurance : 105 ℃ 1000 h to 2000 h
- to 2000 h
- AEC-Q200 compliant (6.3 V to 100 V)
- RoHS compliant

Specifications

Category temp. range	–55 ℃ to +105 ℃	–25 ℃ to +105 ℃
Rated voltage range	6.3 V to 100 V	160 V to 450 V
Capacitance range		
Capacitance tolerance		
Leakage current		
Dissipation factor (tan δ		
Endurance	After following life test with DC voltage and +105 ℃±2 ℃ ripple current value applied (The sum of DC and ripple peak voltage shall not exceed the rated working voltage) for 2000 h, when the capacitors are restored to 20 ℃, the capacitors shall meet the limits specified bellow. Duration 6.3 V to 100 V (ø5 to ø8) : 1000 h, (ø10 to ø18) : 2000 h 160 V to 450 V : 2000 h	
	Capacitance change	Within ±20 % of the initial value
	Dissipation factor (tan δ)	≦ 200 % of the initial limit
	DC leakage current	Within the initial limit
Shelf life	(With voltage treatment)	

Life Derating: 100 uF, 20 V, 105 C, 1000 Hours

10 °C decrease = 2X Life

(at rated voltage)

Life Derating: 100 uF, 20 V, 105 C, 1000 Hours

10 °C decrease = 2X Life

(at rated voltage)

95 °C	2,000 Hours
85 °C	4,000 Hours
75 °C	8,000 Hours
65 °C	*16,000 Hours*
55 °C	*32,000 Hours*

Aluminum Polymer vs. Traditional

POLYMER

The actual product may differ from image shown

Add to compare

Electronic Components KEMET CHARGED

Manufacturer Part No:	A755KS107M1EAAE025
Newark Part No.:	97Y1055

See all Technical Docs

Product Information

Capacitance:	100µF
Voltage Rating:	25V
AE Capacitor Case:	Radial Leaded
Product Range:	A755 Series
ESR:	0.025ohm
Lifetime @ Temperature:	5000 hours @ 105°C
Operating Temperature Min:	-55°C
Operating Temperature Max:	105°C
RoHS Phthalates Compliant:	Yes

HIGH CONDUCTIVITY

ESR: 0.025ohm

ESR: 2.321ohm

TRADITIONAL

The actual product may differ from image shown

Add to compare

ILLINOIS CAPACITOR, INC.

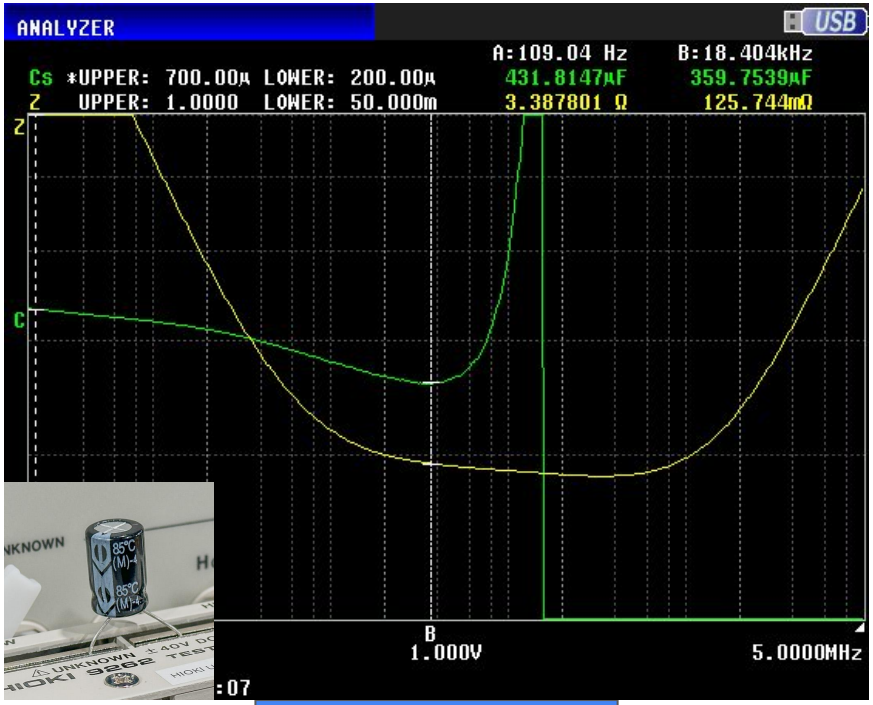
Manufacturer Part No:	107KXM025M
Newark Part No.:	69K8200

See all Technical Docs

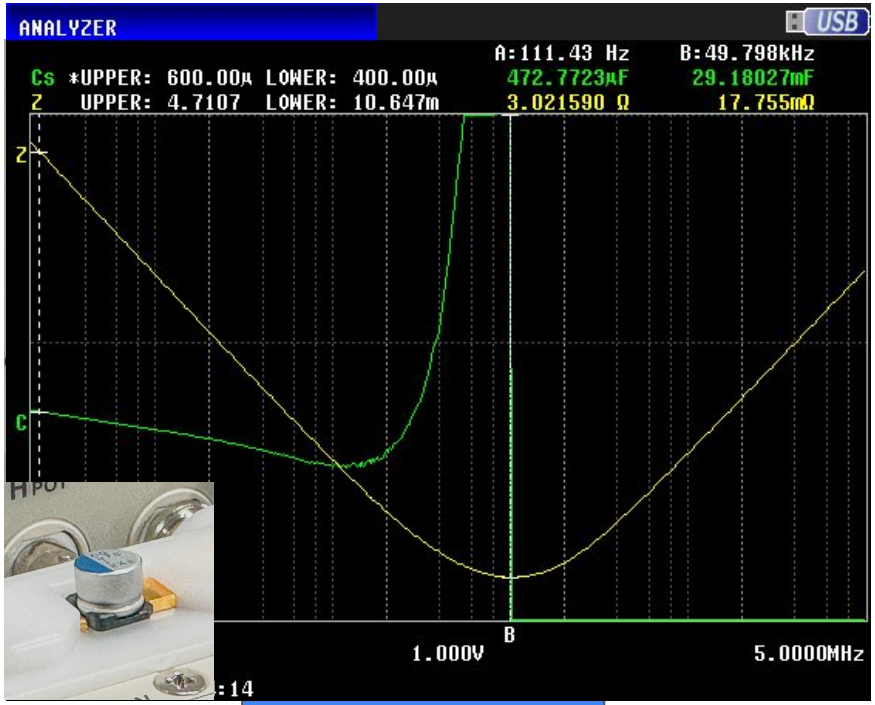
Product Information

Capacitance:	100µF
Voltage Rating:	25V
Product Range:	KXM Series
Capacitance Tolerance:	± 20%
Capacitor Terminals:	Radial Leaded
Operating Temperature Min:	-55°C
Operating Temperature Max:	105°C
Lifetime @ Temperature:	2000 hours @ 105°C
ESR:	2.321ohm
RoHS Phthalates Compliant:	Yes

Aluminum Electrolytic: 470 uF



Traditional (Wet)

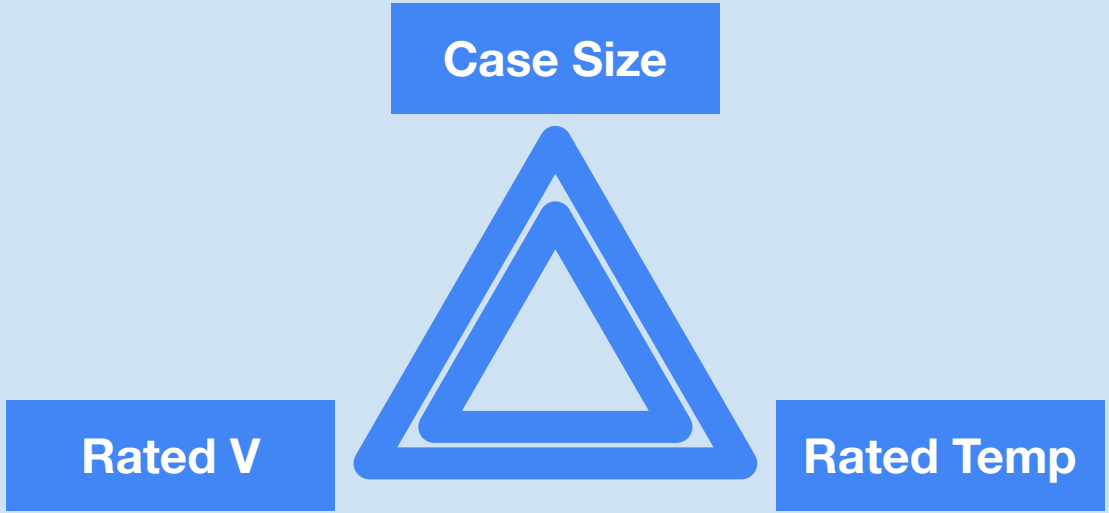


Polymer (Solid)

Part Number: Generic 25V, 470uF Radial

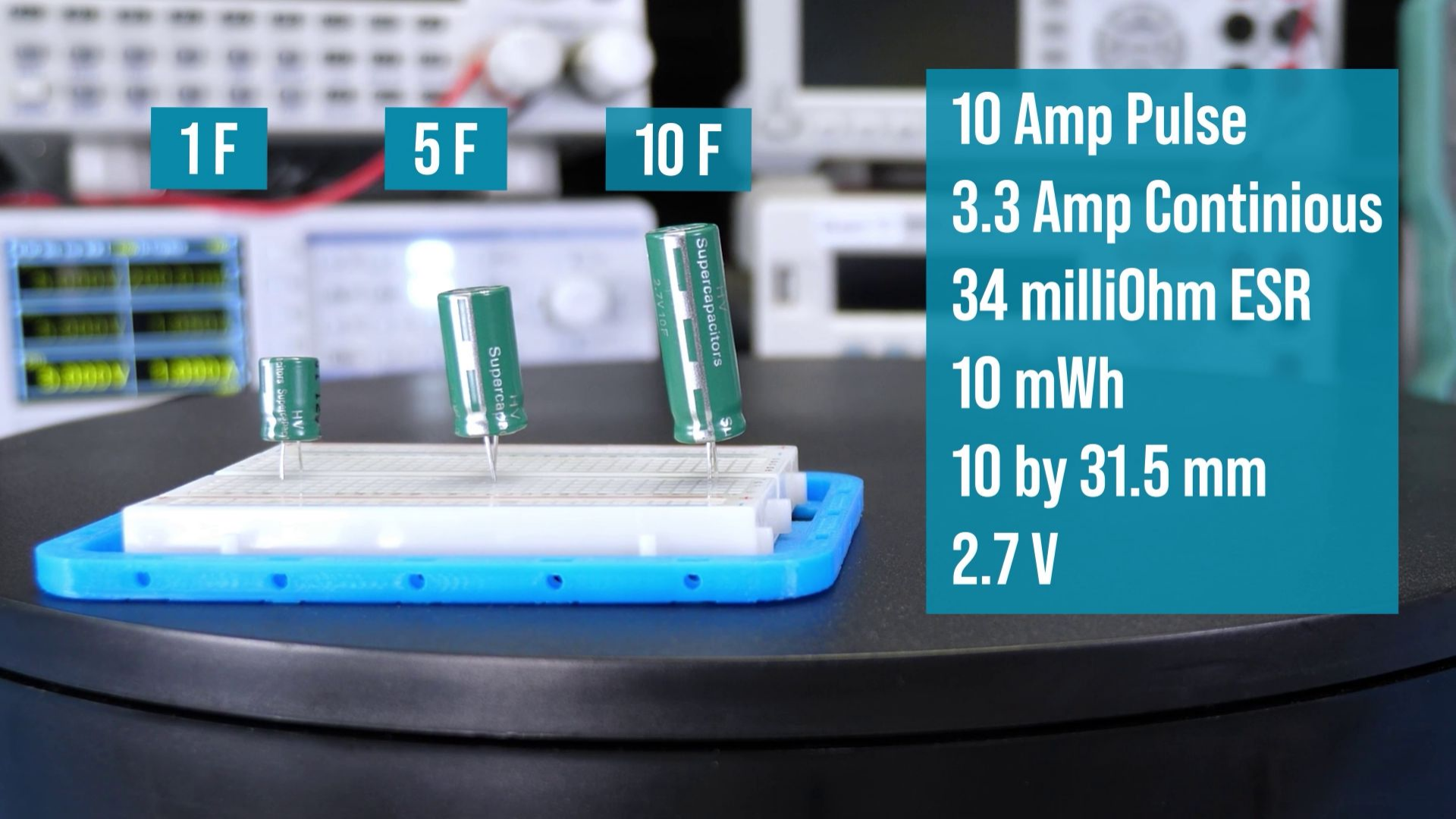
Part Number: nichicon 647-PCG0J471MCL1GS

Aluminum Electrolytic

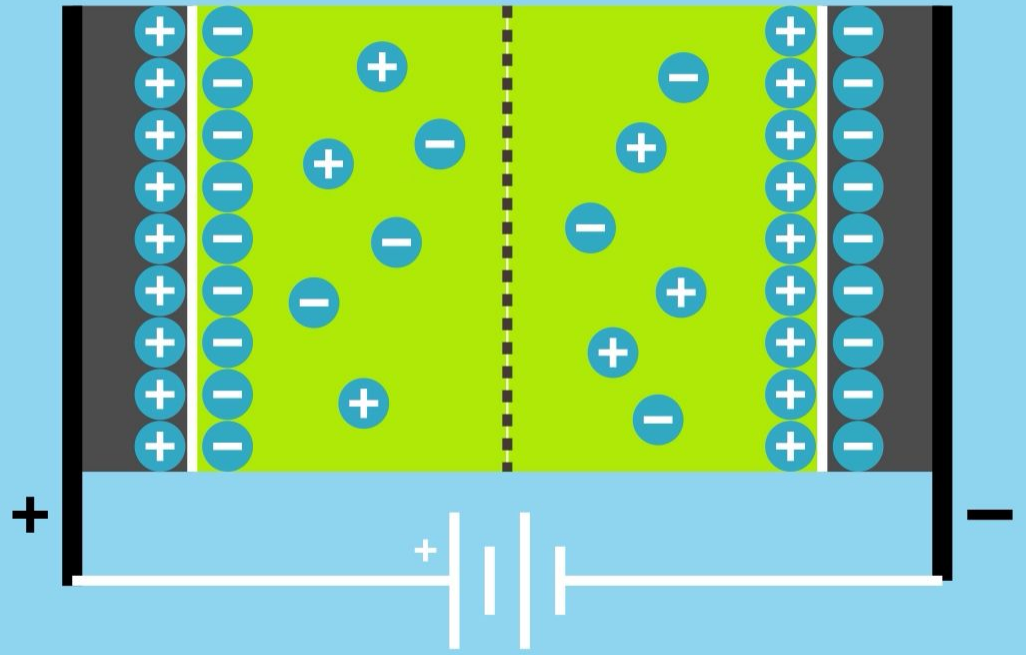


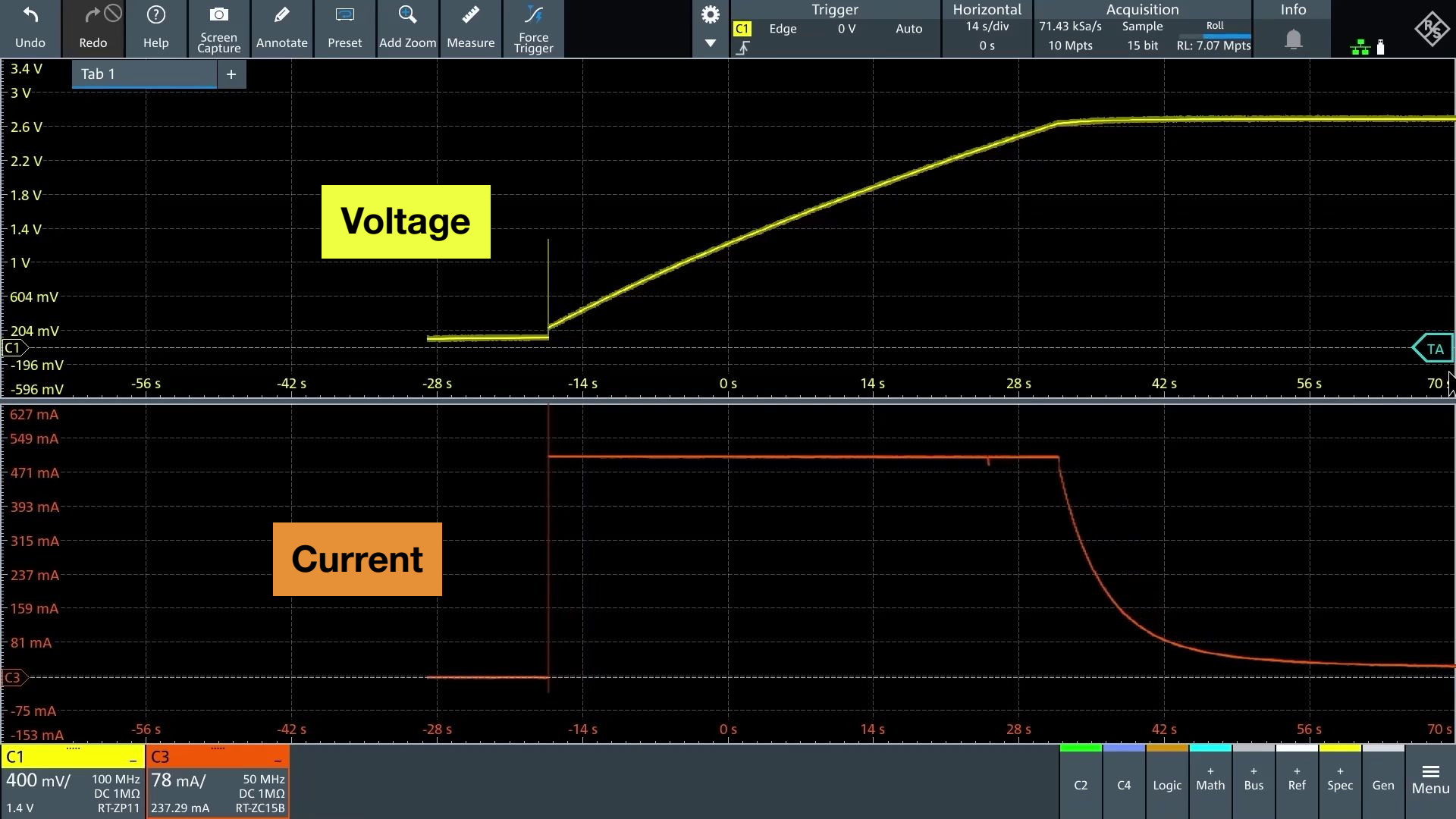
Polymer Means Less ESR

EDLC / Supercapacitors


1 F
5 F
10 F
Supercapacitors
10 Amp Pulse
3.3 Amp Continious
34 milliOhm ESR
10 mWh
10 by 31.5 mm
2.7 V

$$C = \frac{k e_0 A}{d}$$




Undo
Redo
Help
Screen Capture
Annotate
Preset
Add Zoom
Measure
Force Trigger
Trigger
C1 Edge 0 V Auto
Horizontal
14 s/div
0 s
Acquisition
71.43 kSa/s Sample Roll
10 Mpts 15 bit RL: 7.07 Mpts
Info
Tab 1
3.4 V
3 V
2.6 V
2.2 V
1.8 V
1.4 V
1 V
604 mV
204 mV
C1
-196 mV
-596 mV
Voltage
TA
-56 s
-42 s
-28 s
-14 s
0 s
14 s
28 s
42 s
56 s
70 s
627 mA
549 mA
471 mA
393 mA
315 mA
237 mA
159 mA
81 mA
C3
-75 mA
-153 mA
Current
C1
400 mV/
100 MHz
DC 1MΩ
1.4 V
RT-ZP11
C3
78 mA/
50 MHz
DC 1MΩ
237.29 mA
RT-ZC15B
C2
C4
Logic
Math
Bus
Ref
Spec
Gen
Menu

Energy Stored in EDLC (or any capacitor)

$$E = \frac{1}{2} C V_{rail}^{2}$$

Energy Stored in EDLC (or any capacitor)

$$E = \frac{1}{2} C V_{rail}^{2}$$

But can you use it all?

Electrical Double Layer Capacitor (EDLC)

$$E = \frac{1}{2} C V_{rail}^2 - \frac{1}{2} C V_{drop}^2$$

Electrical Double Layer Capacitor (EDLC)

$$E = \frac{1}{2} C V_{rail}^2 - \frac{1}{2} C V_{drop}^2$$

Usable Energy from Capacitor		
Capactiance	2.50	Farad
Vstart	5.3E+0	Volt
Vstop	1.8E+0	Volt
Usable Energy	**31.06**	**Joule**

EDLC (Supercapacitor)

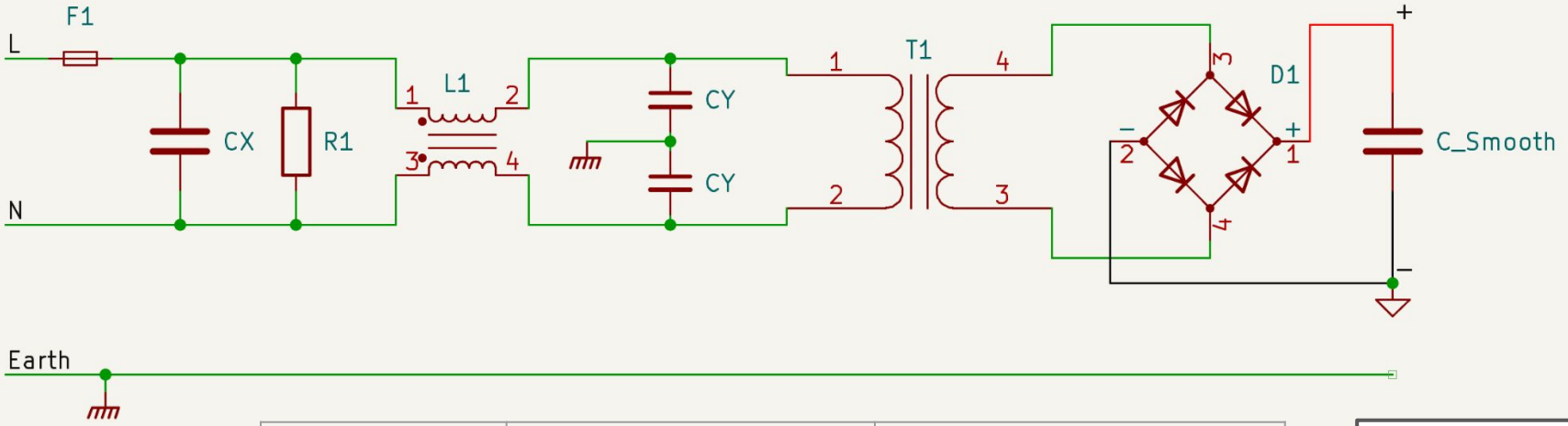
Consider (Dis)charge curves

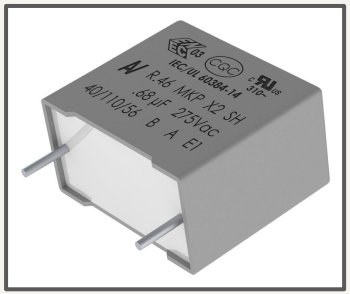
Calculate usable energy

500,000 Charge Cycles

Film
(for EMI)

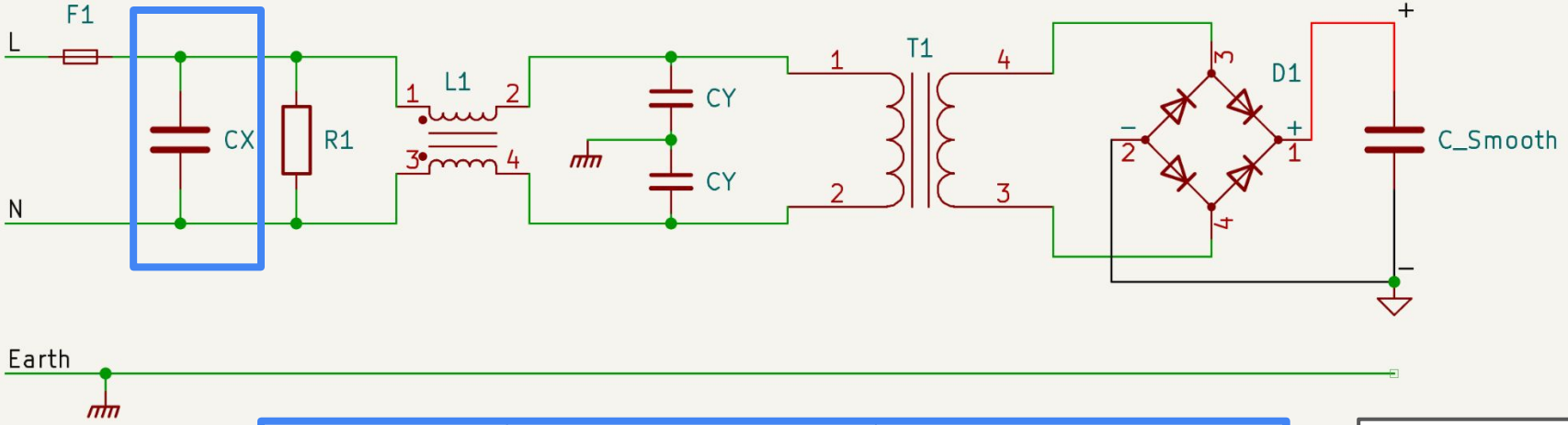
EMI Filter for AC Mains Connection

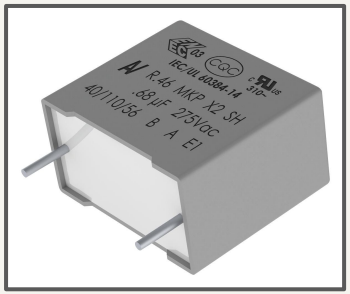




CX	Film or Ceramic	X1 / X2 “Safety Rated” / EMI
CY	Film or Ceramic	Y1 / Y2 “Safety Rated” / EMI
C_Smooth	Electrolytic	High Ripple Current

EMI Filter for AC Mains Connection





CX	Film or Ceramic	X1 / X2 “Safety Rated” / EMI
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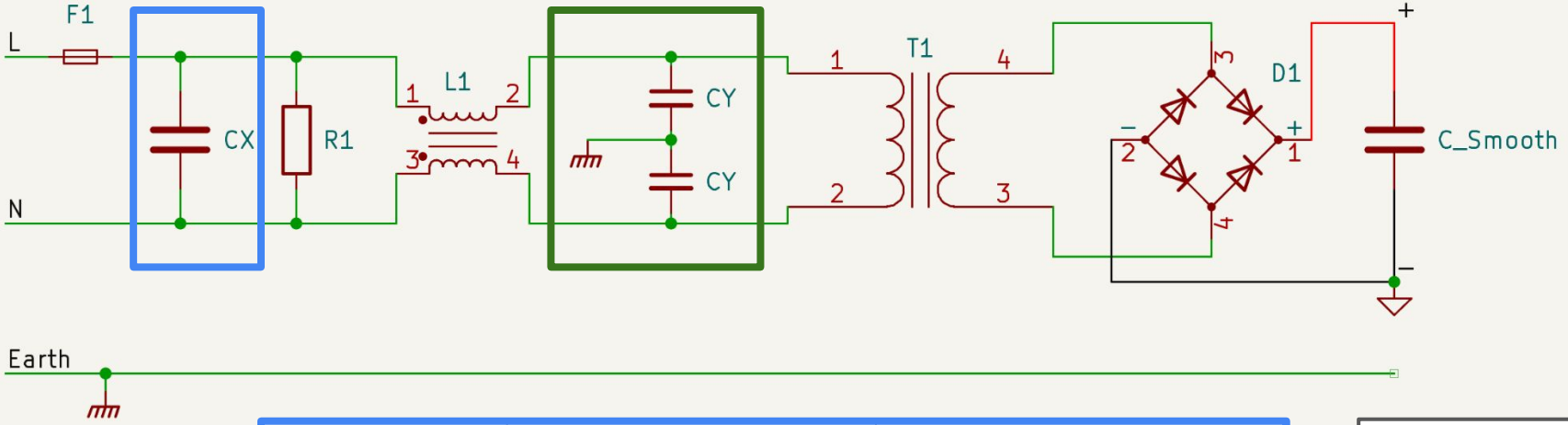
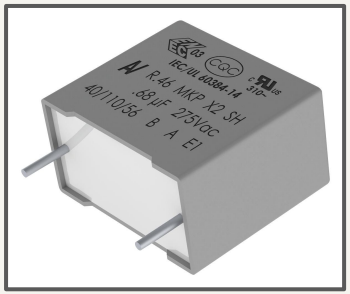
C_Smooth	Electrolytic	High Ripple Current

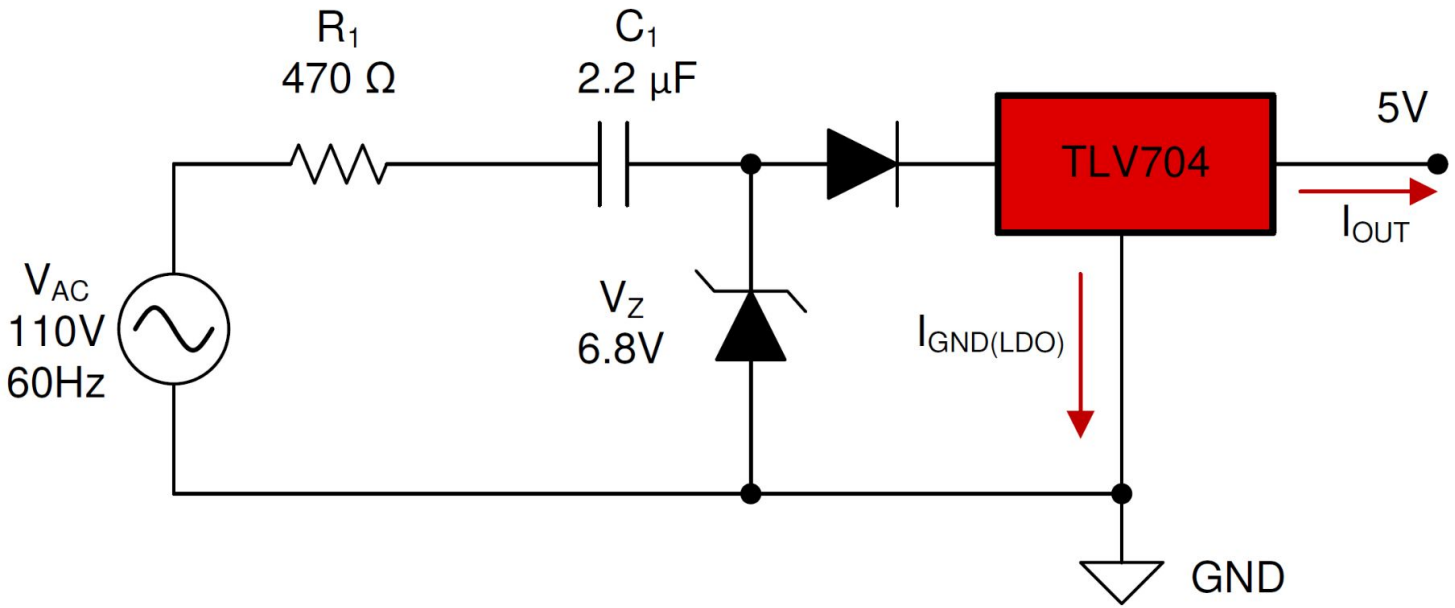
EMI Filter for AC Mains Connection





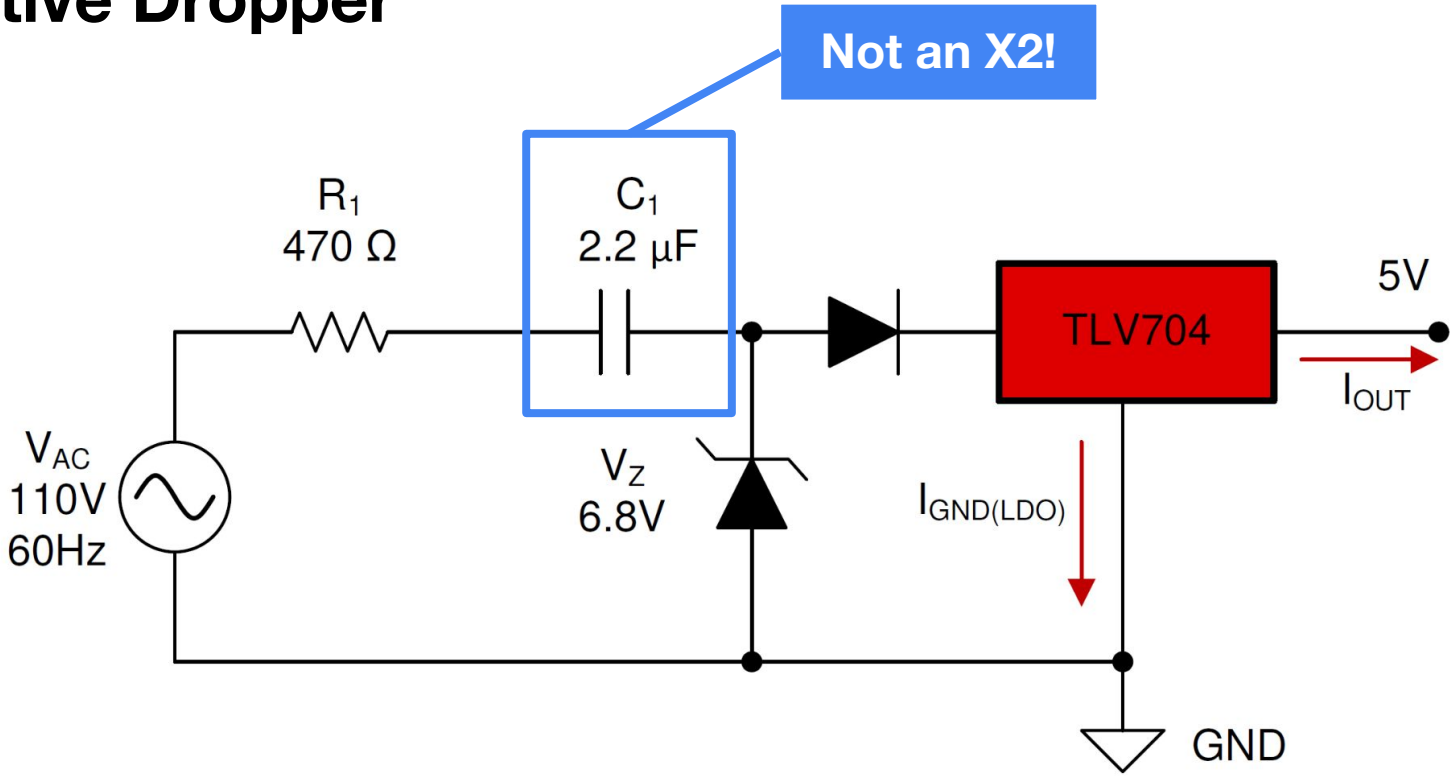
CX	Film or Ceramic	X1 / X2 “Safety Rated” / EMI
CY	Film or Ceramic	Y1 / Y2 “Safety Rated” / EMI
C_Smooth	Electrolytic	High Ripple Current

Capacitive Dropper



Texas Instruments, SBVA079, How to Make a Simple Nonmagnetic AC/DC Power Supply

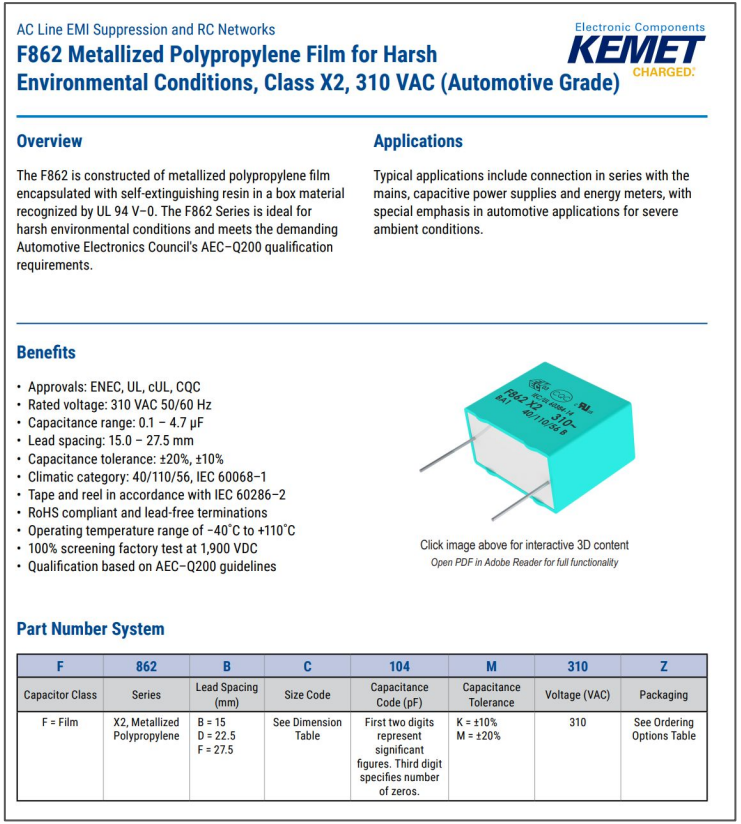
Capacitive Dropper



Texas Instruments, SBVA079, How to Make a Simple Nonmagnetic AC/DC Power Supply

EMI Suppression / X & Y Capacitors

- X2 Capacitors
- Many approvals… but:
  - UL94
    - Flammability of Plastic
  - IEC/UL 60384-14
    - Fixed Capacitors for **Electromagnetic Interference Suppression** and Connection to the Supply Mains
- **Series-coupling = limited life**



AC Line EMI Suppression and RC Networks

Electronic Components

KEMET CHARGED.

F862 Metallized Polypropylene Film for Harsh Environmental Conditions, Class X2, 310 VAC (Automotive Grade)

Overview

The F862 is constructed of metallized polypropylene film encapsulated with self-extinguishing resin in a box material recognized by UL 94 V–0. The F862 Series is ideal for harsh environmental conditions and meets the demanding Automotive Electronics Council's AEC–Q200 qualification requirements.

Applications

Typical applications include connection in series with the mains, capacitive power supplies and energy meters, with special emphasis in automotive applications for severe ambient conditions.

Benefits

- Approvals: ENEC, UL, cUL, CQC
- Rated voltage: 310 VAC 50/60 Hz
- Capacitance range: 0.1 – 4.7 µF
- Lead spacing: 15.0 – 27.5 mm
- Capacitance tolerance: ±20%, ±10%
- Climatic category: 40/110/56, IEC 60068–1
- Tape and reel in accordance with IEC 60286–2
- RoHS compliant and lead-free terminations
- Operating temperature range of –40°C to +110°C
- 100% screening factory test at 1,900 VDC
- Qualification based on AEC–Q200 guidelines

Click image above for interactive 3D content

Open PDF in Adobe Reader for full functionality

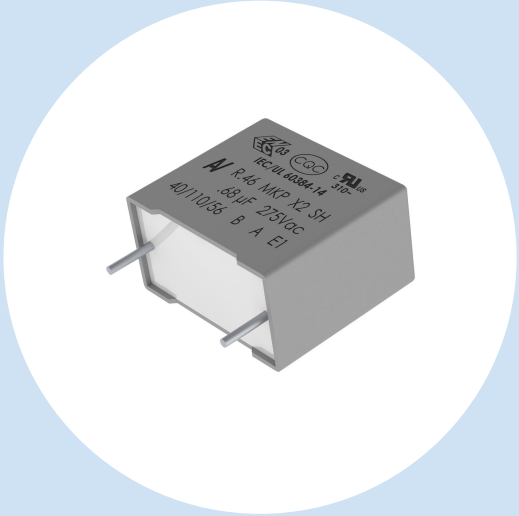
Part Number System

F	862	B	C	104	M	310	Z
Capacitor Class	Series	Lead Spacing (mm)	Size Code	Capacitance Code (pF)	Capacitance Tolerance	Voltage (VAC)	Packaging
F = Film	X2, Metallized Polypropylene	B = 15 D = 22.5 F = 27.5	See Dimension Table	First two digits represent significant figures. Third digit specifies number of zeros.	K = ±10% M = ±20%	310	See Ordering Options Table

Film (EMI)

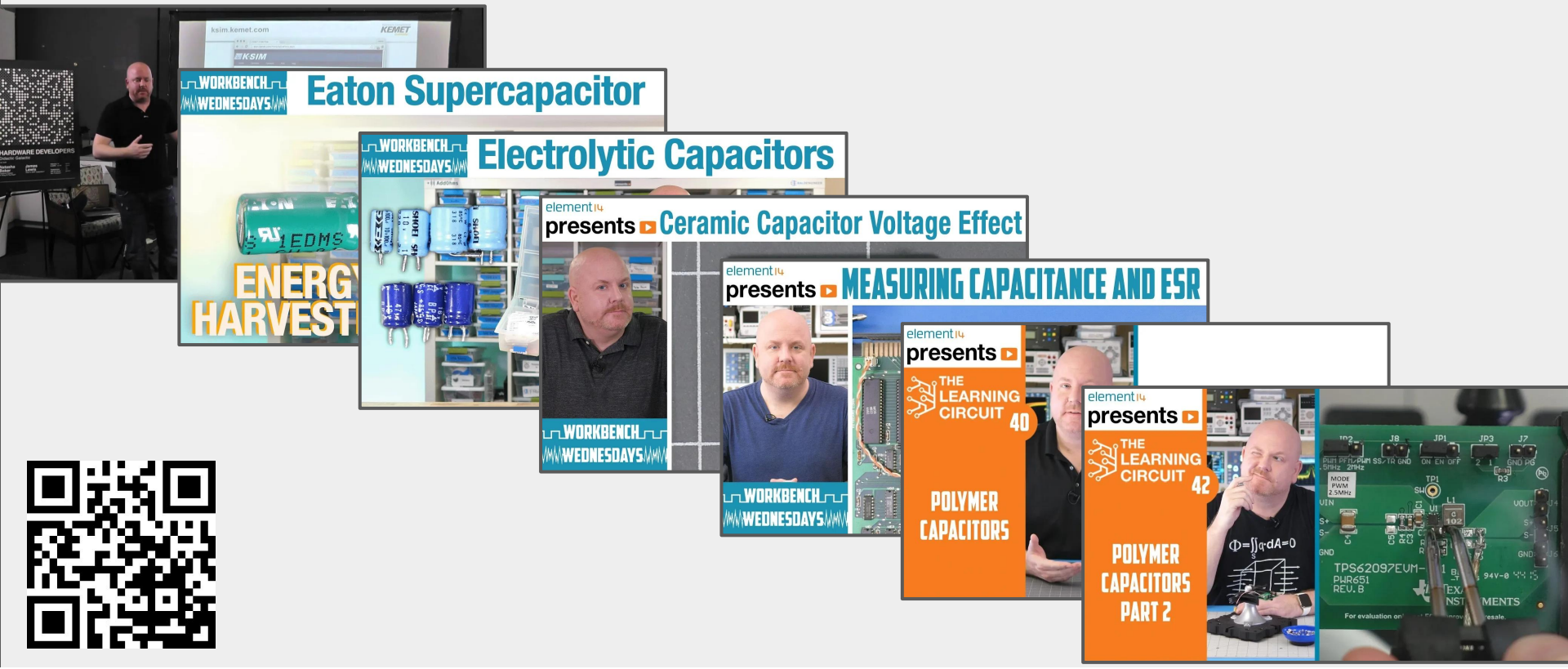
Cx = Across the Line
Cy = Line to Earth Ground

Not rated for Series Coupling



Resources

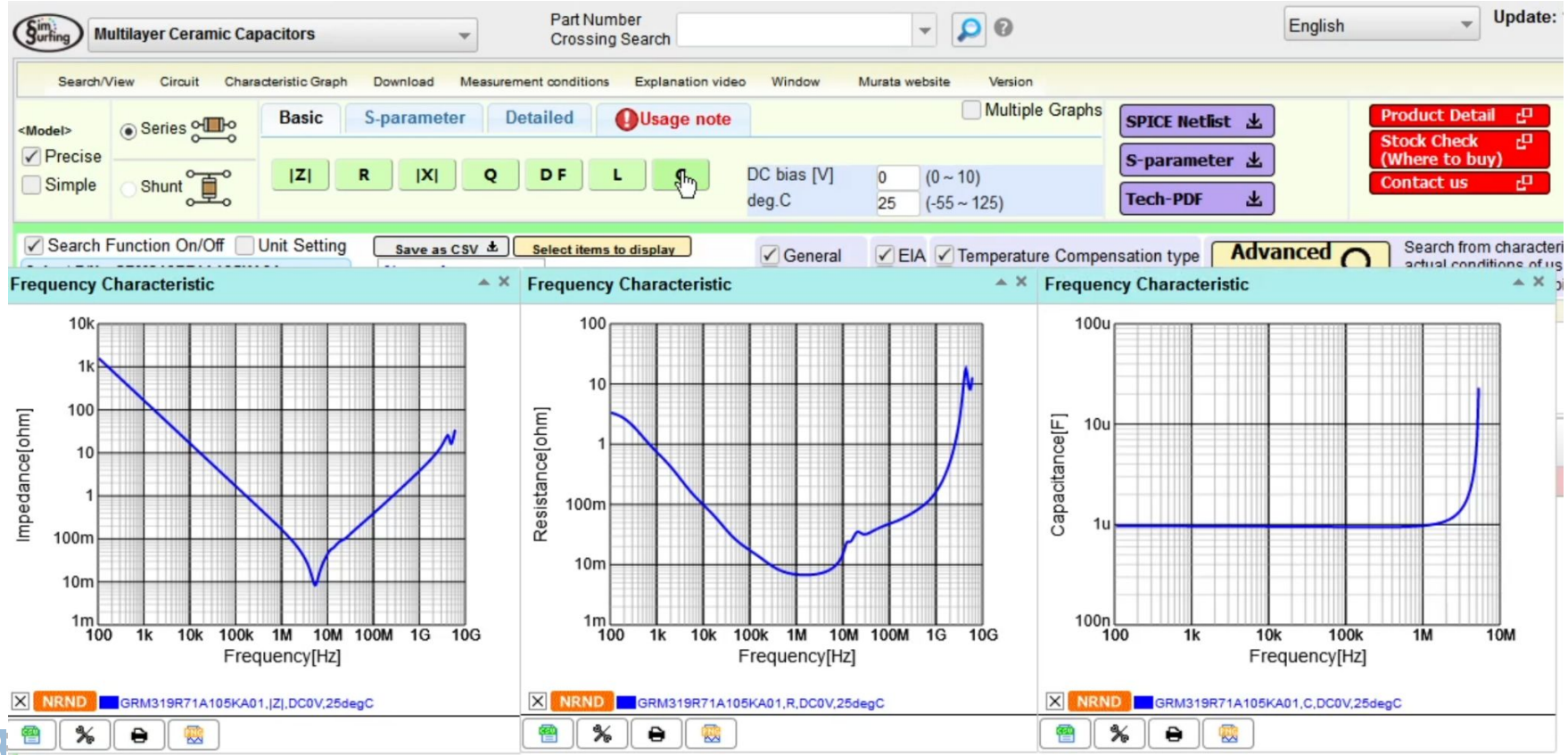
Capacitor Video Playlist



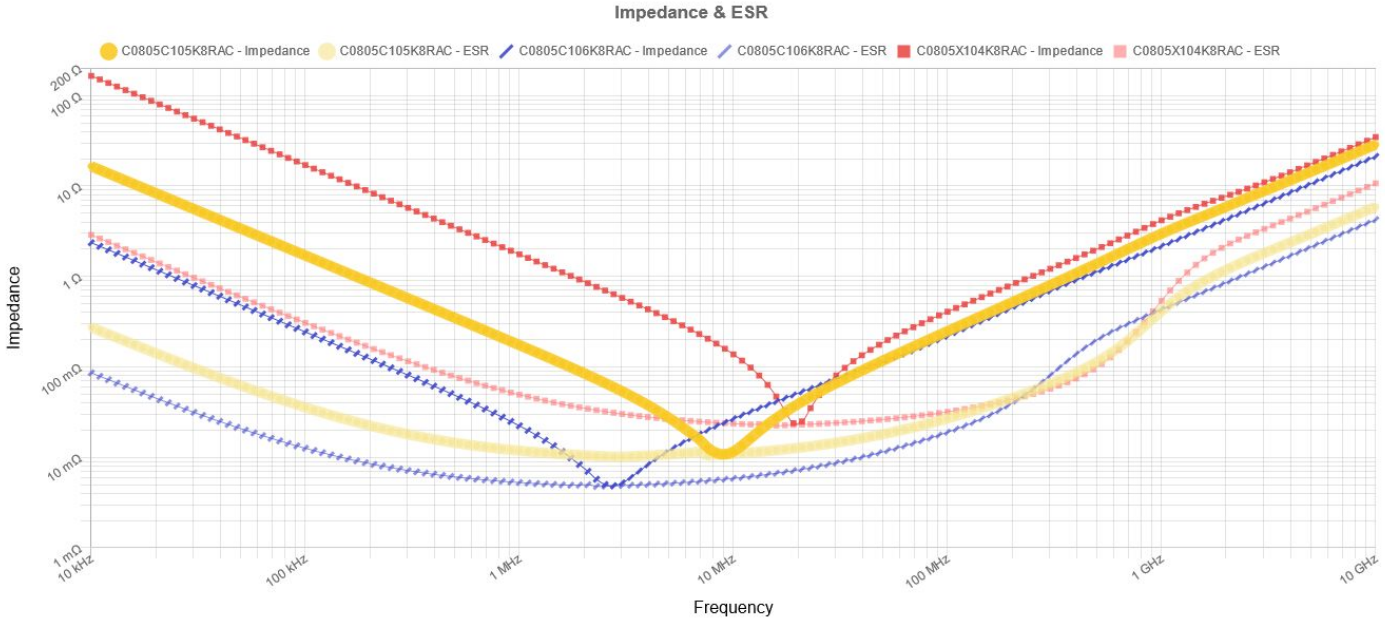
bald.ee/**capvids**

BALDENGINEER

Murata SimSurfing - Impedance Example



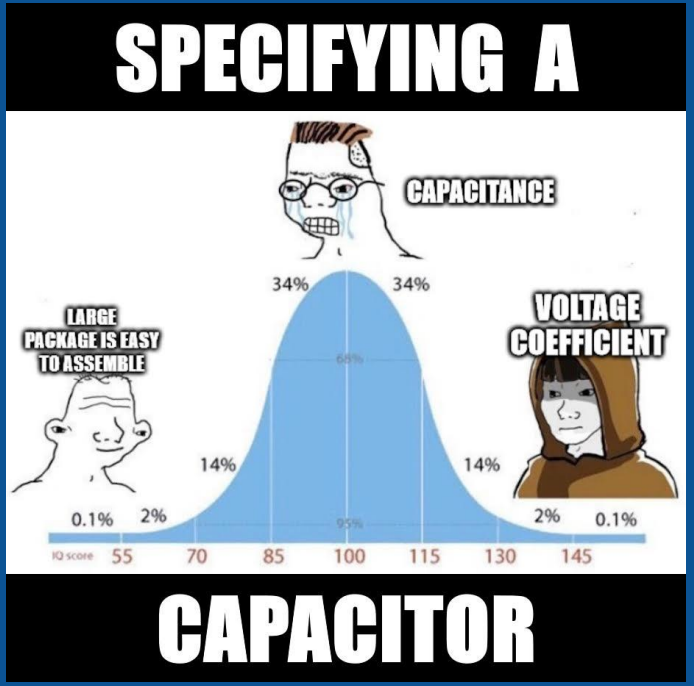
KEMET KSIM: 100n, 1u, 10u - Ceramic Z/ ESR



Info	Legend	Tolerance	Part Number	Cap.	V_{DC}*	Dielectric	Qty.	Bias (V)	Amb. (°C)	Add	Remove
>	●	10%	**C0805C105K8RAC**	**1 uF**	**10**	**X7R**	1	0	25	+	×
>	/	10%	C0805C106K8RAC	10 uF	10	X7R	1	0	25	+	×
>	■	10%	C0805X104K8RAC	100 nF	10	X7R	1	0	25	+	×

Circuit Break MacroFab Podcast

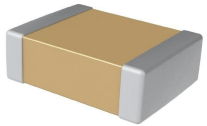
#434: The Other VCC



macrofab.com/podcasts/capacitor-comparison-voltage-coefficient/

High-Level Comparison

(Yes, there are exceptions in every case.)

	Type	Capacitance	Voltage	ESR / Z	Lifetime
	Non-Polar	Low (C0G) Mid, High (X5R/X7R)	Low to Med (< 200 V)	Low	Long
	Non-Polar	Low to Med	Med to High (>50 V)	Low	Very long
	Polarized	High	High (< 400 V)	Med	Low to Med
	Polarized	High	Low (< 50 V)	MnO2: High Polymer: Low	Very long
	Polarized	High	Low (<5 V)	Low to Med	Long
	Polarized	Med to High	Med to high (12, 50, 100 V)	Med to High	Long

Thank You

BALDENGINEER

+ AddOhms

mastodon://
baldengineer@qoto.org

Links…

bald.ee / **teardown2024**