Electronic Components

KEMET

CHARGED.®

Not All Caps Are Created Equal…….

November 4, 2015

IEEE – Long Island Chapter – EMC Society

AGENDA

- Overview
- Capacitor Grades
- Capacitor Fundamentals
- Ceramics
  - Construction
  - Characteristics
- Tantalum & Polymers
  - Construction
  - Characteristics
- Decoupling
- Film
  - Construction
  - Characteristics
  - Products
- Tokin Products
  - EMI Cores
  - Flex suppressors
- K-Sim (formally Kemet SPICE)

KEMET Offers 98% of Dielectric Solutions

Electronic Components KEMET CHARGED®

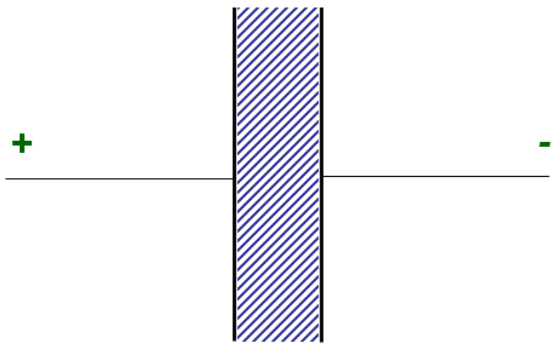
Product Development Drivers

"More Capacitance in a Smaller Package for less Cost"

Electronic Components KEMET CHARGED.

- Size Constraints & Miniaturization
- Robust, high reliability
  - ✓ Mechanical and Electrical
- Lower Parasitics
  - ✓ ESR
  - ✓ ESL
- Higher
  - ✓ Energy Density
  - ✓ Power Density
  - ✓ Frequency
  - ✓ Voltage
  - ✓ Temperature
  - ✓ Vibration
- Application Specific Requirements
  - ✓ Custom Solutions
- Cost reductions
  - ✓ Material set optimization
  - ✓ Manufacturing efficiencies

Capacitance = εA/d



ε = Dielectric Constant

A = Active area on plates

d = dielectric thickness

Dielectric Comparison Chart

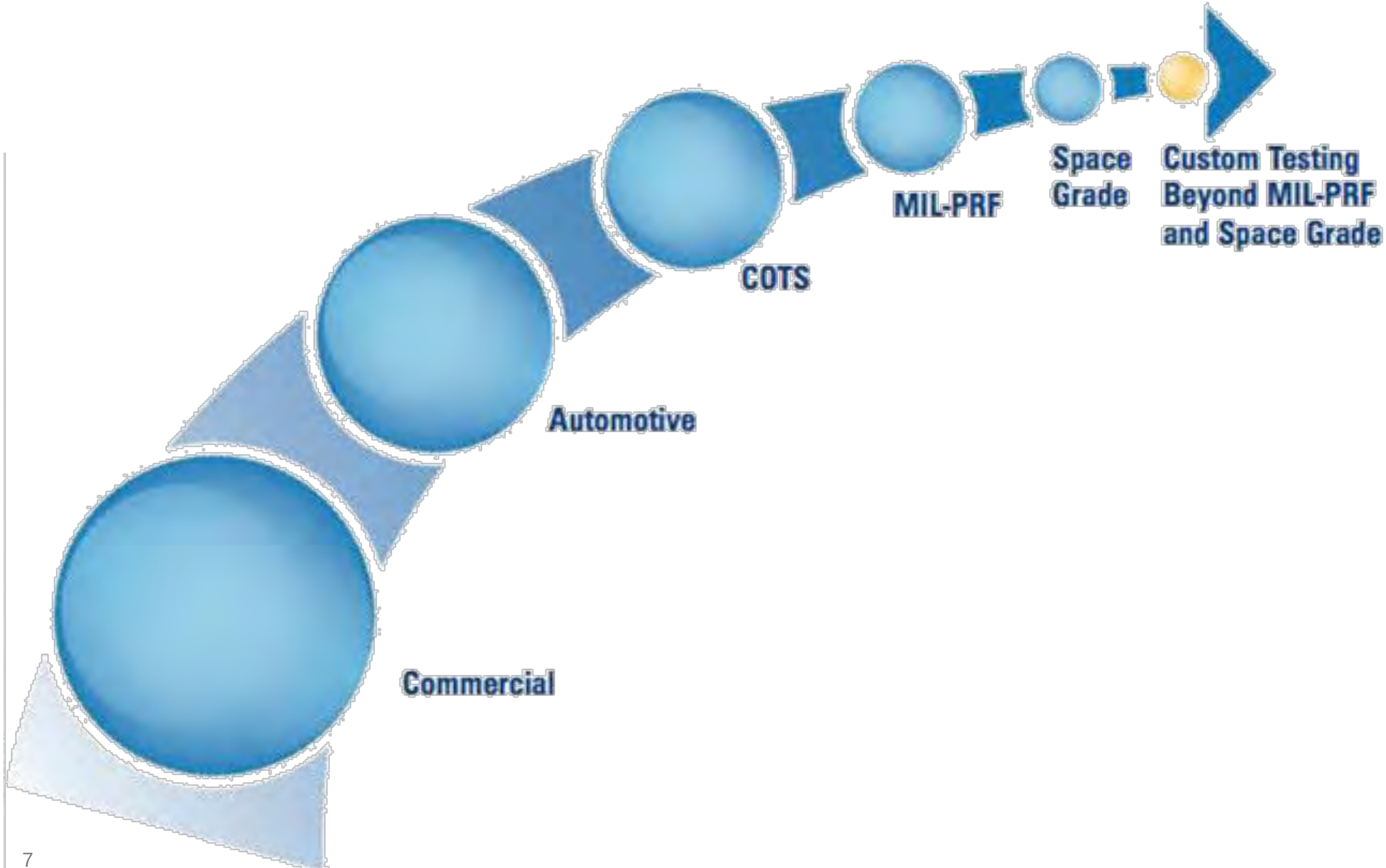
Electronic Components KEMET CHARGED.

Characteristic	PET (MKT)	PEN (MKN)	PPS (MKI)	PP MKP/KP	COG (NPO)	X7R	X8R	Tantalum MnO2	Tantalum Polymer	Aluminum Polymer	Aluminum Electrolytic
Operating Temperature Range (°C)	-55° to 125°	-55° to 125°	-55° to 140°	-55° to 105°	-55° to 125°	-55° to 125°	-55° to 150°	-55° to 125°	-55° to 105° -55° to 125°	-55° to 105° -55° to 125°	-55° to 105°
Temperature characteristic (C/C)	± 5%	± 5%	± 1.5 %	± 1.5%	0 ± 30ppm	± 15 %	± 10 %	± 10%	± 10%	± 10%	25 to -30%
DC Voltage Coefficient (%) at Vr	Negligible	Negligible	Negligible	Negligible	Negligible	-20%	± 15 %	Negligible	Negligible	Negligible	10 to -15%
Aging Rate (%hr/Decade)	Negligible	Negligible	Negligible	Negligible	Negligible	2%	1%	N.A.	N.A.	N.A.	N.A.
Dissipation Factor (%) 1 KHz		0.8	0.2	0.05	0.1	2.5	3.5	8	8	8	5
10 KHz	1.5	1.5	0.25	0.5	0.1						20
100 KHz	3.0	3.0	0.5	1							
ESR	low	low	very low	very low	low	Moderate to high	Moderate to high	high	Low to Moderate	Low to Moderate	high
Insulation Resistance (MΩxµF) 25°C	10,000	10,000	10,000	10,000	10,000	1,000	1,000	100	10	17	500
85°C	1,000	1,000	1,000	1,000	1,000	500	200	10	1	1.7	5
Dielectric absorption (DA) (%)	0.5	1	0.2	0.05	0.6	2.5	1	0.5	0.5	0.5	N.A.
Capacitance Range	1000pF to 10µF	1000pF to 6.8µF	100pF to 1µF	100pF to 10µF	0.5pF to 1µF	100pF to 4.7µF	100pF to 1µF	0.1µF to 1500µF	10µF to 1500µF	6.8µF to 470µF	0.1µF to 100µF
Capacitance Tolerances (± %)	5; 10	5; 10	2.5; 5	5; 10; 20	5; 10	10; 20	5; 10; 20	5;10; 20	20	20	-20 +50
Failure Mode	Open	Open	Open	Open	Short	Short	Short	Short	Short	Short	Short
Self Healing	Yes	Yes	Limited	Yes	No	No	No	Limited	Limited	Limited	Limited
Reliability	High	High	High	High	High	Moderate	Moderate	High	High	High	Low
Piezoelectric effect	No	No	No	No	No	Yes	Yes	No	No	No	
Resistance to thermal and mechanical shock	High	High	High	High	Low	Moderate to Low	Low	High	High	High	
Non-Linear distortion (3rd harmonic)	Very Low	Very Low	Very Low	Very Low	Low	High	High	N.A.	N.A.	N.A	High
Polar	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
260°C Pb-Free Capable	Not Yet	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No

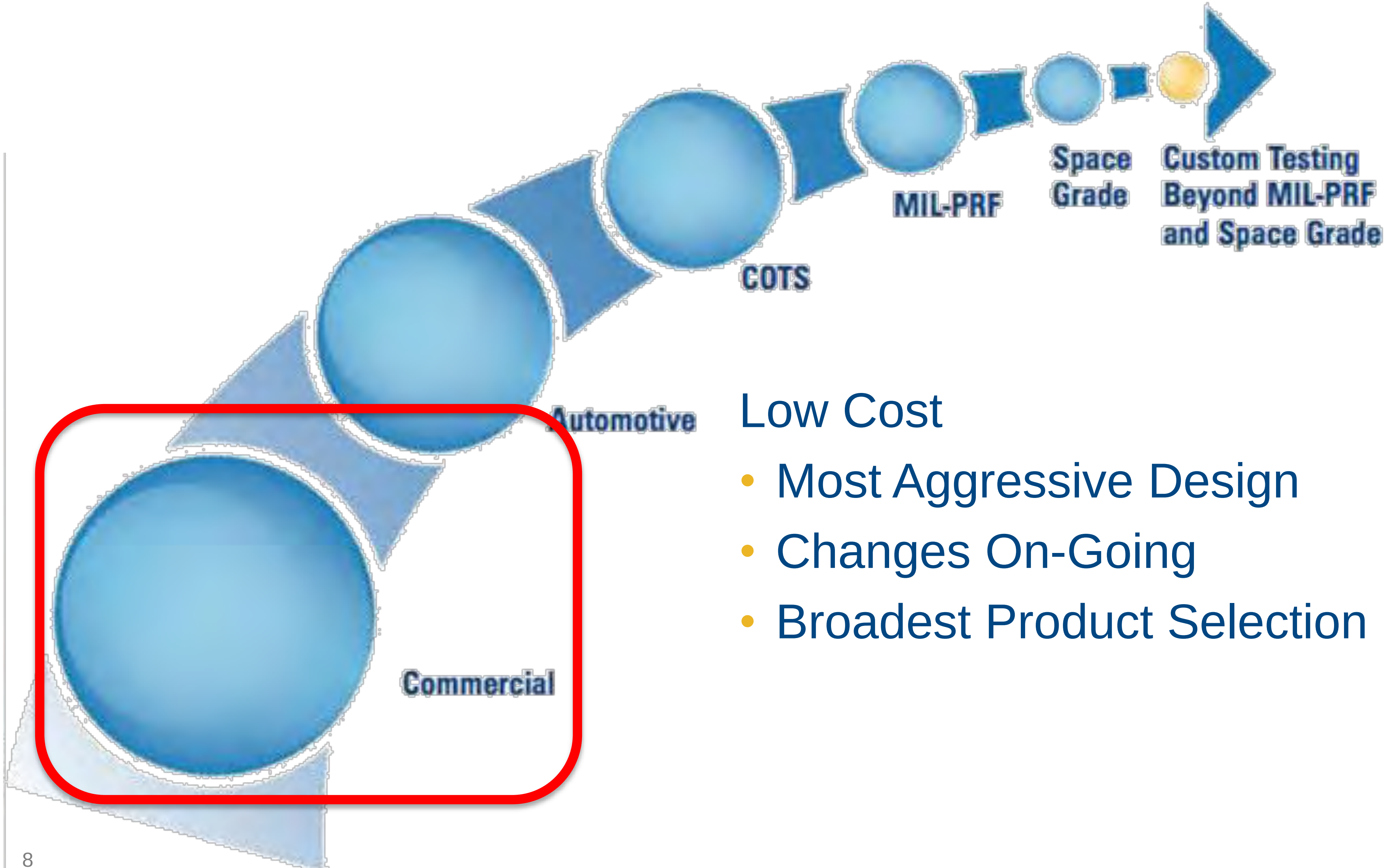
Differences in Capacitor Grades

Low Voltage DC Applications

Product Grades



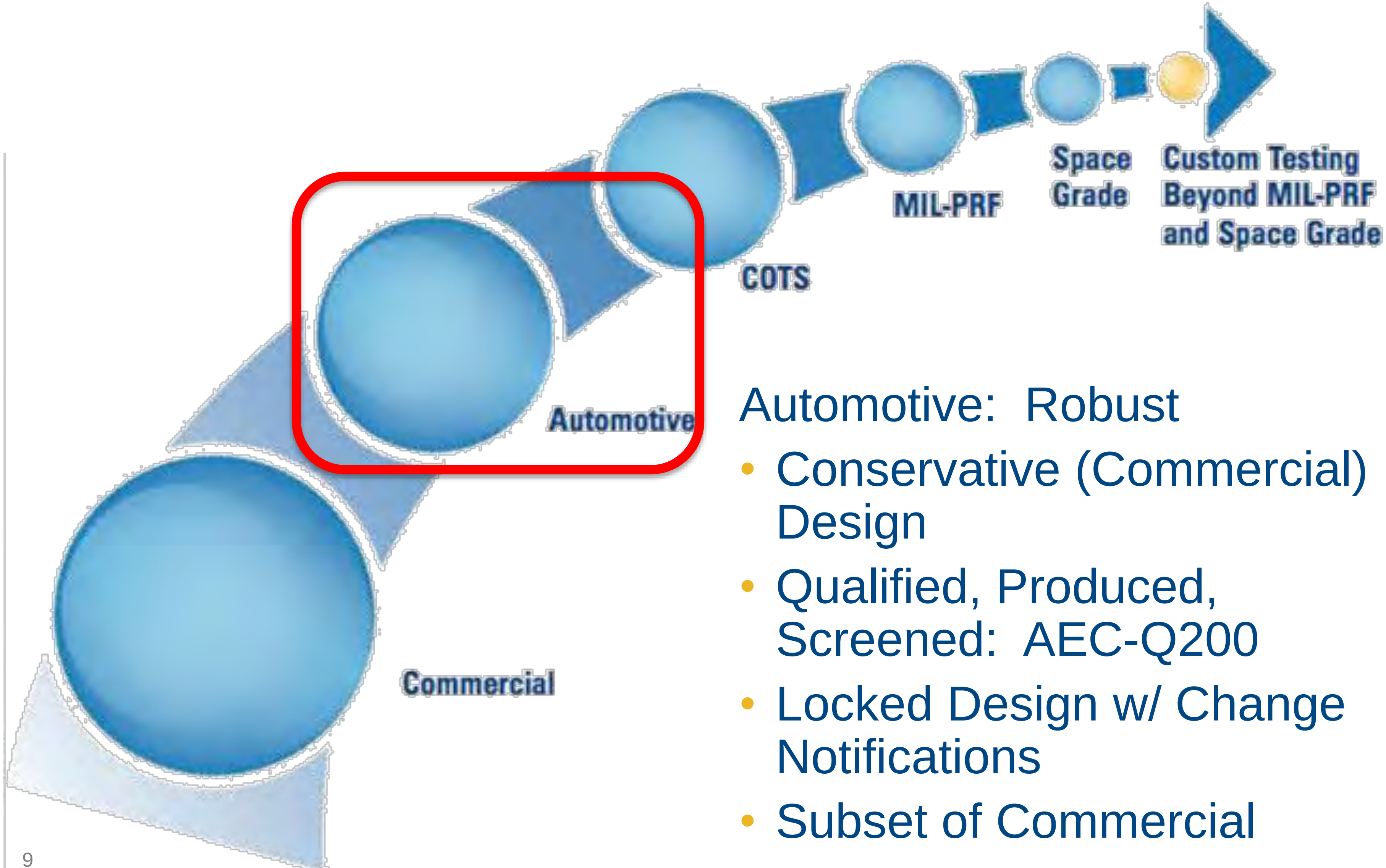
Commercial



Low Cost

- Most Aggressive Design
- Changes On-Going
- Broadest Product Selection

Automotive



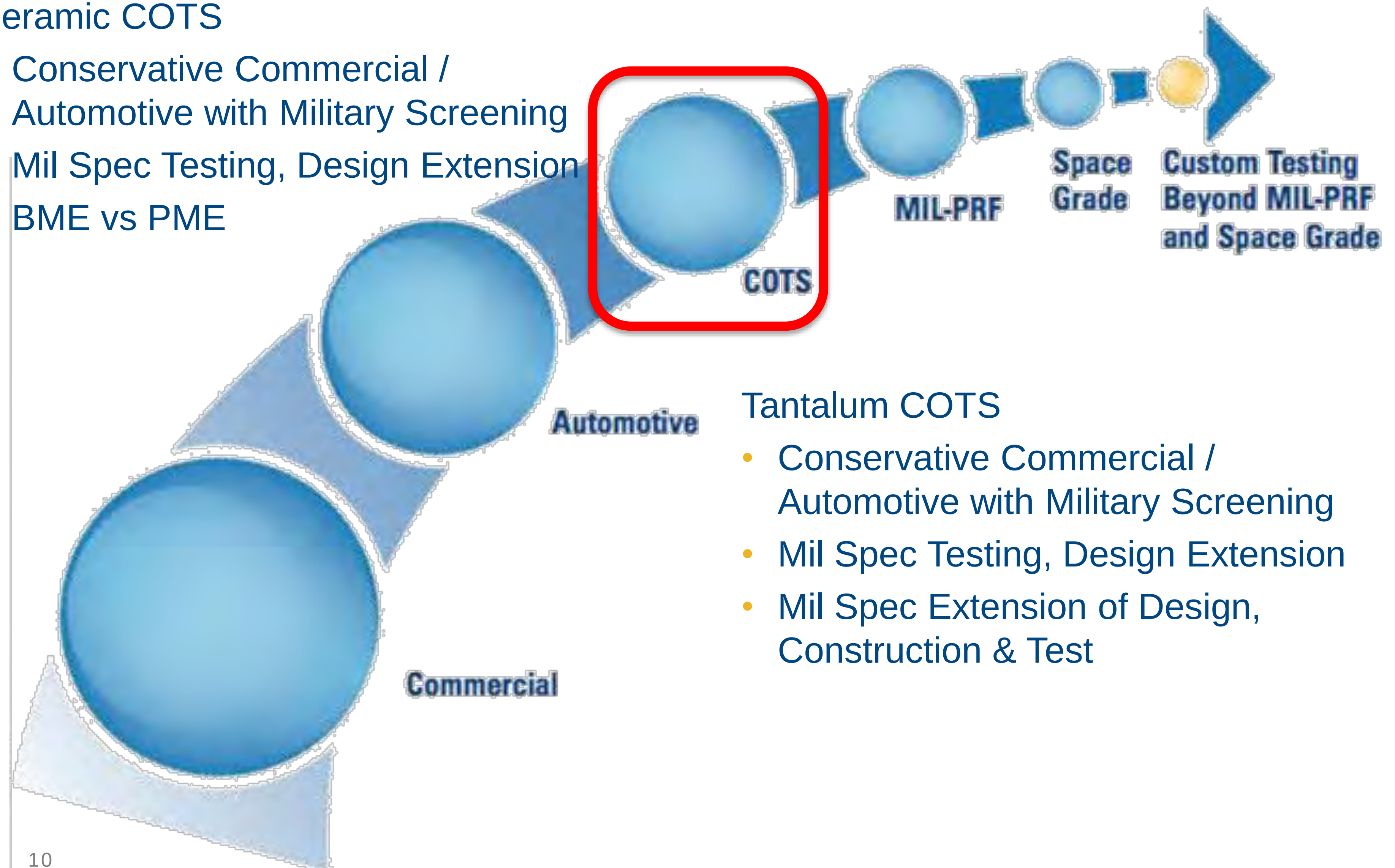
Automotive: Robust

- Conservative (Commercial) Design
- Qualified, Produced, Screened: AEC-Q200
- Locked Design w/ Change Notifications
- Subset of Commercial

COTS (Commercial "Off-The-Shelf")

Ceramic COTS

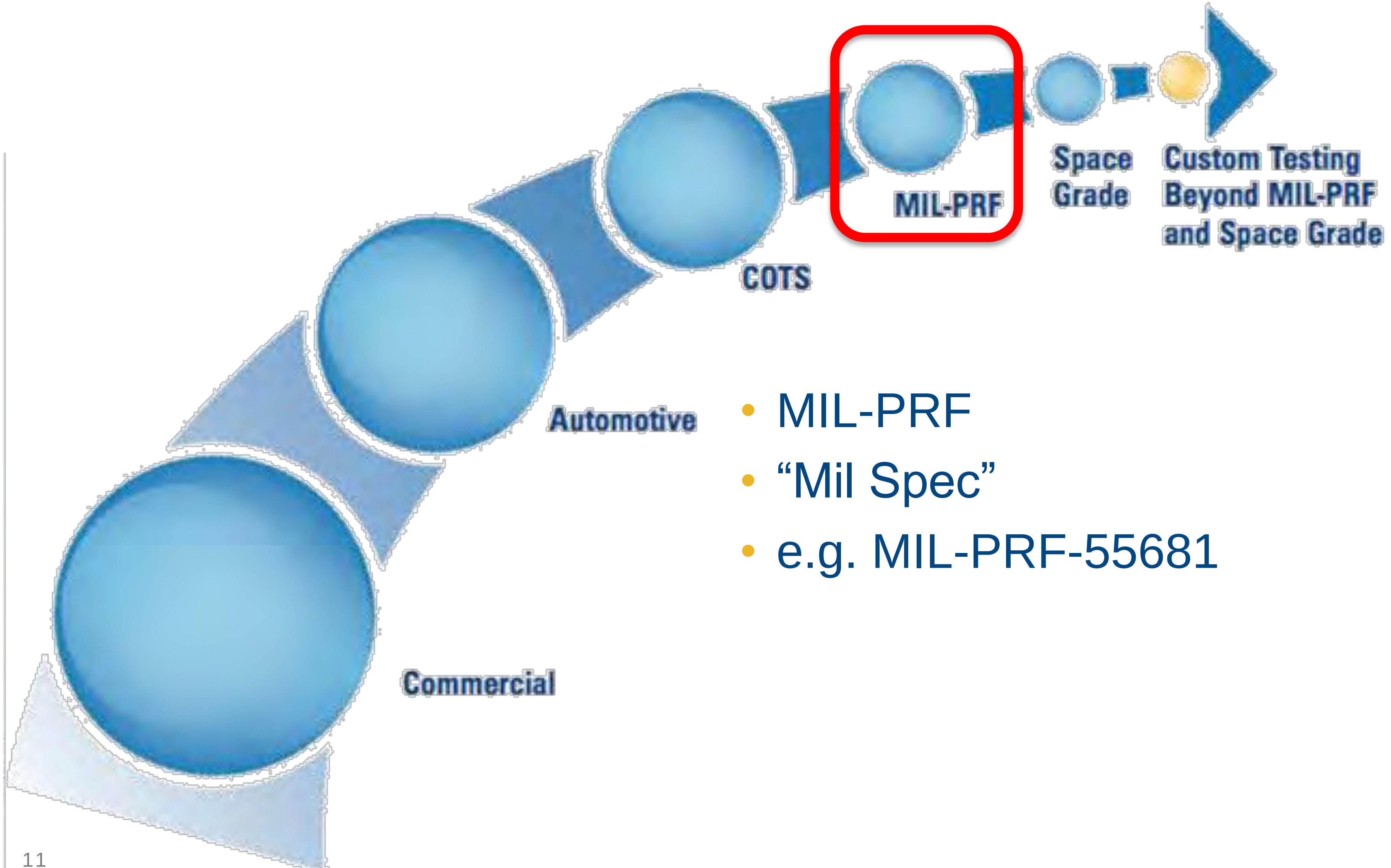
- Conservative Commercial / Automotive with Military Screening
- Mil Spec Testing, Design Extension
- BME vs PME



Tantalum COTS

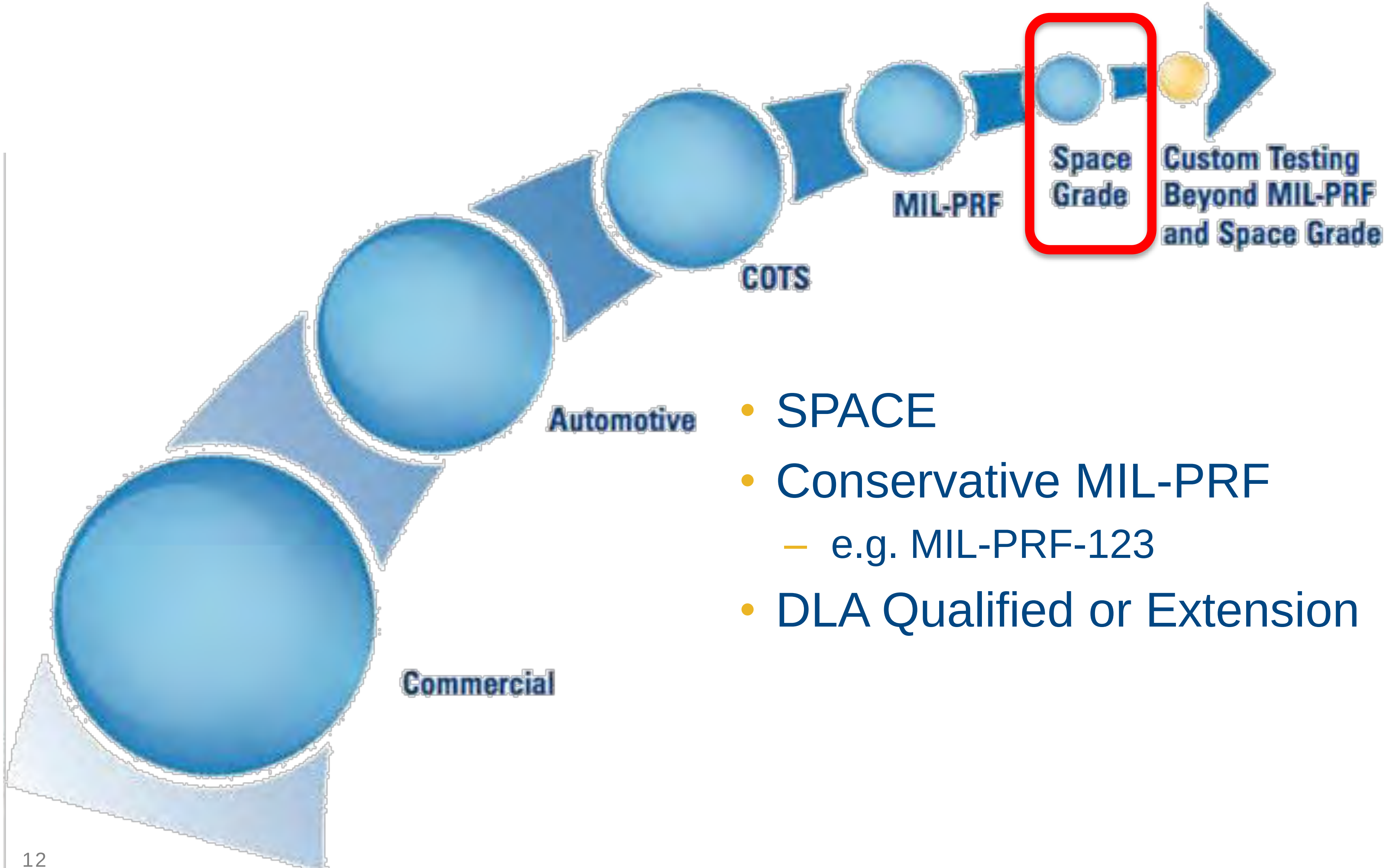
- Conservative Commercial / Automotive with Military Screening
- Mil Spec Testing, Design Extension
- Mil Spec Extension of Design, Construction & Test

MIL-PRF



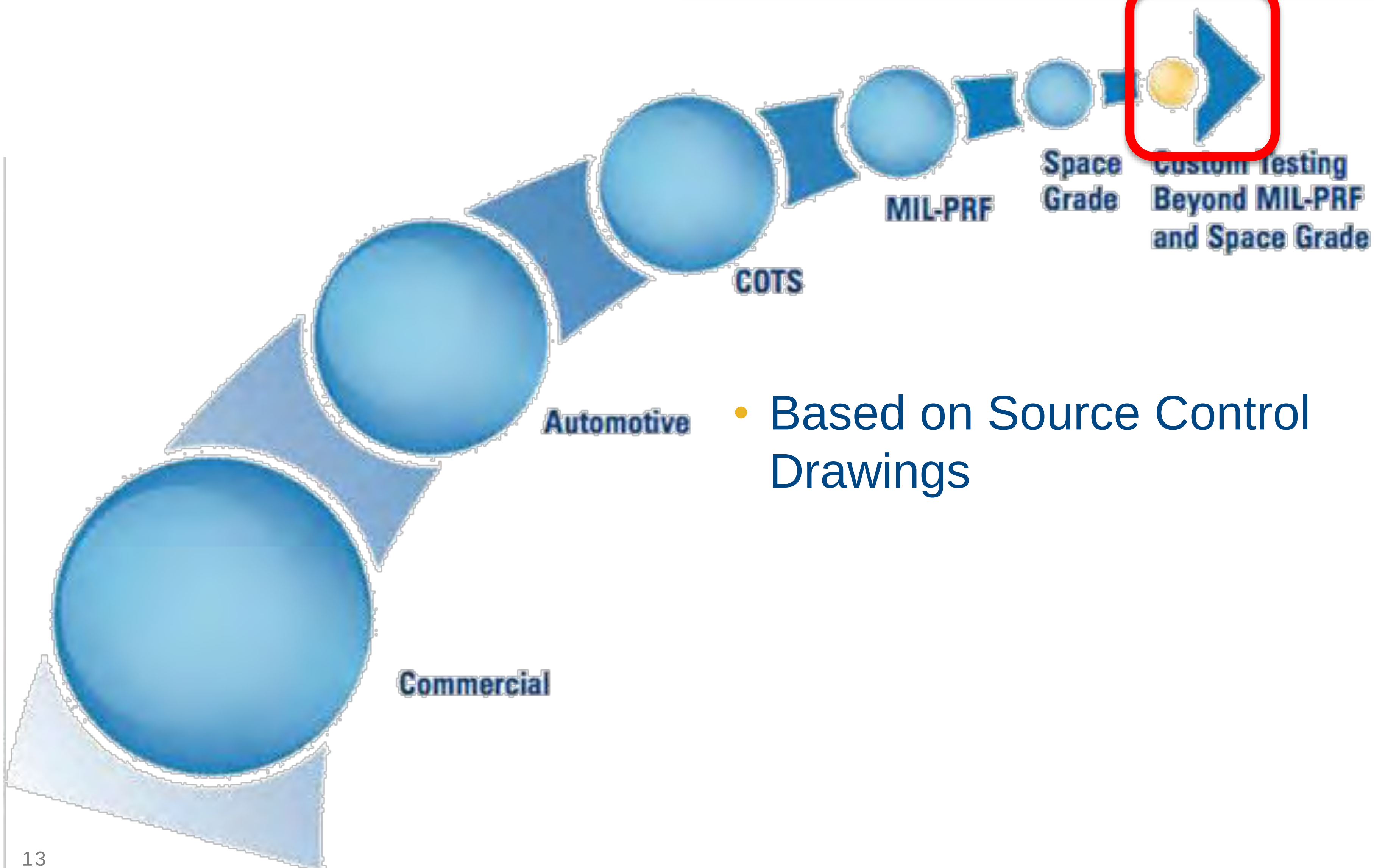
- MIL-PRF
- “Mil Spec”
- e.g. MIL-PRF-55681

Space Grade



- SPACE
- Conservative MIL-PRF
  - e.g. MIL-PRF-123
- DLA Qualified or Extension

Custom



- Based on Source Control Drawings

Capacitor Grade Examples

Electronic Components KEMET CHARGED

The Capacitance Company KEMET CHARGED

Surface Mount Multilayer Ceramic Chip Capacitors (SMD MLCCs)

Commercial Off-the-Shelf (COTS) for Higher Reliability Applications, X7R Dielectric, 6.3VDC-200VDC

Overview

KEMET's COTS program is an extension of our capability and knowledge regarding high reliability test criteria and requirements. As an established and trusted supplier of "up-screened" products, the COTS program was developed in response to the growing demand within the defense, aerospace, automotive, medical and consumer electronics industries for lower cost and commercially available products that offers the same high quality and high reliability as up-screened products. The COTS program addresses this demand and integrates commercial grade products with high reliability testing and inspection protocols that provide the accelerated conditioning and 100% screening necessary to eliminate infant mortal failures from the population.

KEMET's X7R dielectric features a 125°C maximum operating

All COTS testing includes voltage conditioning and post-electrical testing as per MIL-PRF-55681. For enhanced reliability, KEMET offers the following test level options and conformance certifications:

Electronic Components KEMET CHARGED

High Reliability KEMET Organic Capacitor (KO-CAP)

T540 Polymer Commercial Off-the-Shelf (COTS) Series

Overview

The KEMET Organic Capacitor (KO-CAP) is a tantalum capacitor with a Ta anode and Ta_2O_5 dielectric. A conductive organic polymer replaces the traditionally used MnO_2 as the cathode plate of the capacitor. This results in very low ESR and improved capacitance retention at high frequency. The KO-CAP may also be operated at steady state voltages at up to 90% of rated voltage for part types with rated voltages of ≤ 10 volts and up to 80% of rated voltage for part types > 10 volts.

The T540 Series KO-CAP offers the same advantages as the T525 Series but is also designed for the Commercial Off-the-Shelf (COTS) requirements of defense and aerospace applications. This surface mount product offers a tin lead (SnPb) leadframe finish, surge current testing options and standard or low ESR levels.

Benefits

- Polymer cathode technology
- 125°C maximum operating temperature
- High frequency capacitance retention
- Benign failure mode

Applications

Typical applications include decoupling and filtering in defense and aerospace applications that require low ESR or a benign failure mode.

Electronic Components KEMET CHARGED

Surface Mount Multilayer Ceramic Chip Capacitors (SMD MLCCs)

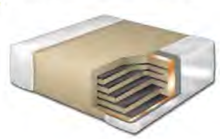
C0G Dielectric, 10 – 200 VDC (Commercial Grade)

Overview

KEMET's C0G dielectric features a 125°C maximum operating temperature and is considered "stable." The Electronics Components, Assemblies & Materials Association (EIA) characterizes C0G dielectric as a Class I material. Components of this classification are temperature compensating and are suited for resonant circuit applications or those where Q and stability of capacitance characteristics are required. C0G exhibits no change in capacitance with respect to time and voltage and boasts a negligible change in capacitance with reference to ambient temperature. Capacitance change is limited to ±30 ppm/°C from -55°C to +125°C.

Benefits

- -55°C to +125°C operating temperature range
- RoHS Compliant
- EIA 0201, 0402, 0603, 0805, 1206, 1210, 1808, 1812, 1825, 2220, and 2225 case sizes
- DC voltage ratings of 10 V, 16 V, 25 V, 50 V, 100 V, and 200 V
- Capacitance offerings ranging from 0.5 pF up to 0.47 µF
- Available capacitance tolerances of ±0.10 pF, ±0.25 pF, ±0.5 pF, ±1%, ±2%, ±5%, ±10%, and ±20%
- No piezoelectric noise
- Extremely low ESR and ESL
- High thermal stability
- High ripple current capability
- Preferred capacitance solution at line frequencies and into the MHz range
- No capacitance change with respect to applied rated DC voltage
- Negligible capacitance change with respect to temperature from -55°C to +125°C
- No capacitance decay with time
- Non-polar device, minimizing installation concerns
- 100% pure matte tin-plated termination finish allowing for excellent solderability
- SnPb plated termination finish option available upon request (5% minimum)



Ordering Information

Electronic Components KEMET CHARGED

MIL–PRF (CWR Style) Established Reliability

T409 Series CWR09 Style MIL–PRF–55365/4

Overview

The KEMET T409 Series is approved to MIL-PRF-55365/4 (CWR09) with Weibull failure rates of B level (0.1% failures per 1,000 hours), C level (0.01% failures per 1,000 hours), D level (0.001% failures per 1,000 hours), or T level (0.01% failures per 1,000 hours, Option C surge current, DPA, Radiographic inspection, 100% visual inspection, DCL and ESR measurements within +3 standard deviations, and Group C inspection). This CWR09 product is a precision-molded device with compliant terminations and indelible laser marking. Tape and reeling per EIA 481-1 is standard.

Benefits

- Established reliability options
- Taped and reeled per EIA 481–1
- Symmetrical, compliant terminations
- Laser-marked case
- 100% surge current test available on all case sizes
- Qualified to MIL–PRF–55365/4, Style CWR09
- Termination options B, C, H, K
- Weibull failure options B, C, D, and T
- Exponential failure rates M, P, R, S
- Voltage rating of 4 – 50 VDC
- Operating temperature range of -55˚C to +125˚C

Applications

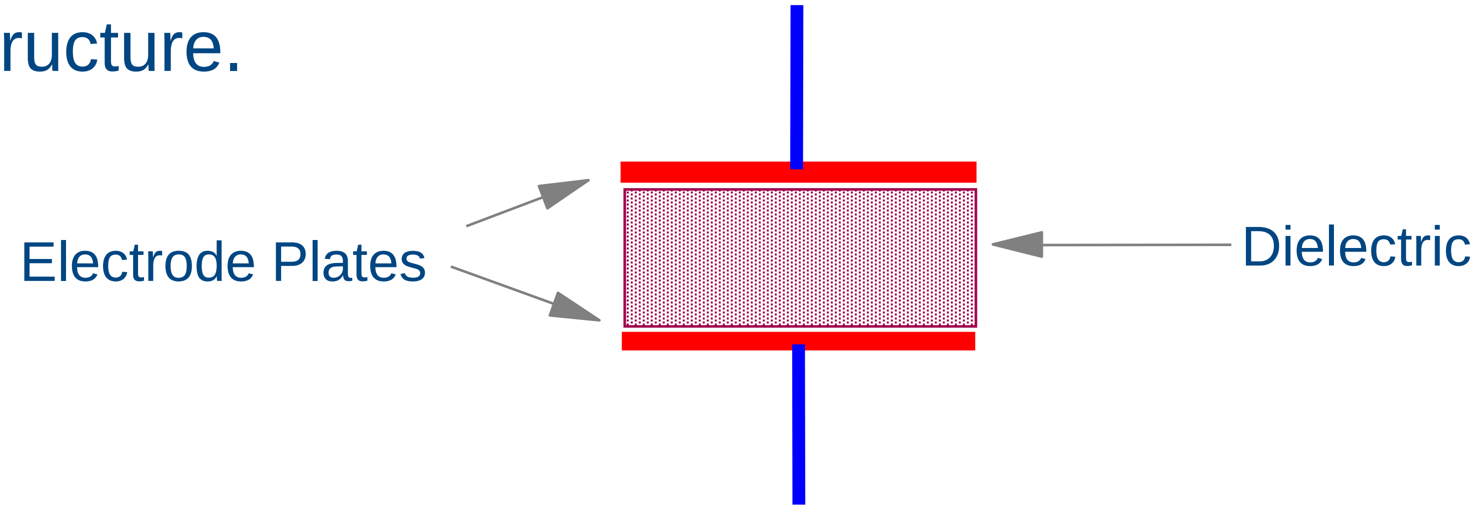
Typical applications include decoupling and filtering in Military and aerospace applications requiring CWR09 devices.

Capacitor Fundamentals

Parasitics

Common Structure

All capacitors utilize the same basic mechanism in their structure.



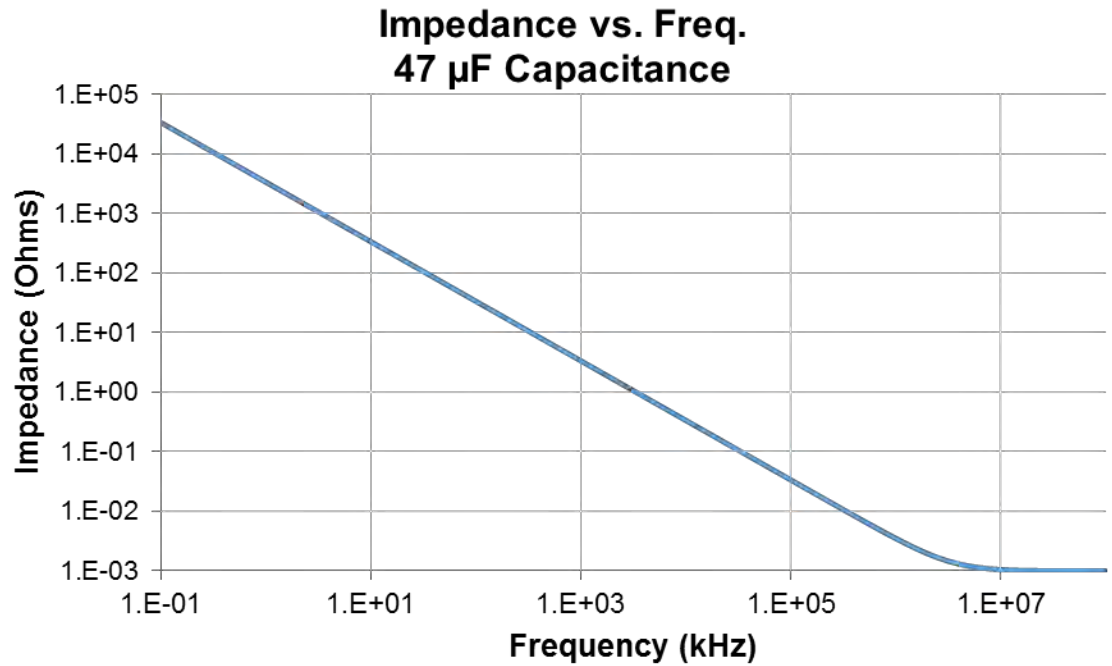
The value of a capacitor is measured in farads. For 1 farad of capacitance, 1 coulomb of charge is stored on the plates, when 1 volt of force is applied.

1 farad = 1 coulomb / 1 volt

1 coulomb represents ~ 6 x 10^{19} electrons

"Pure" Capacitor

$$Z = X_C = \frac{1}{2\pi f C}$$

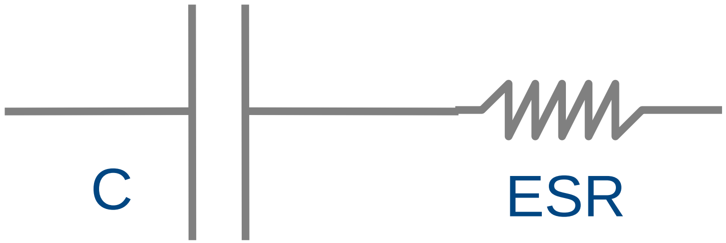


Where:

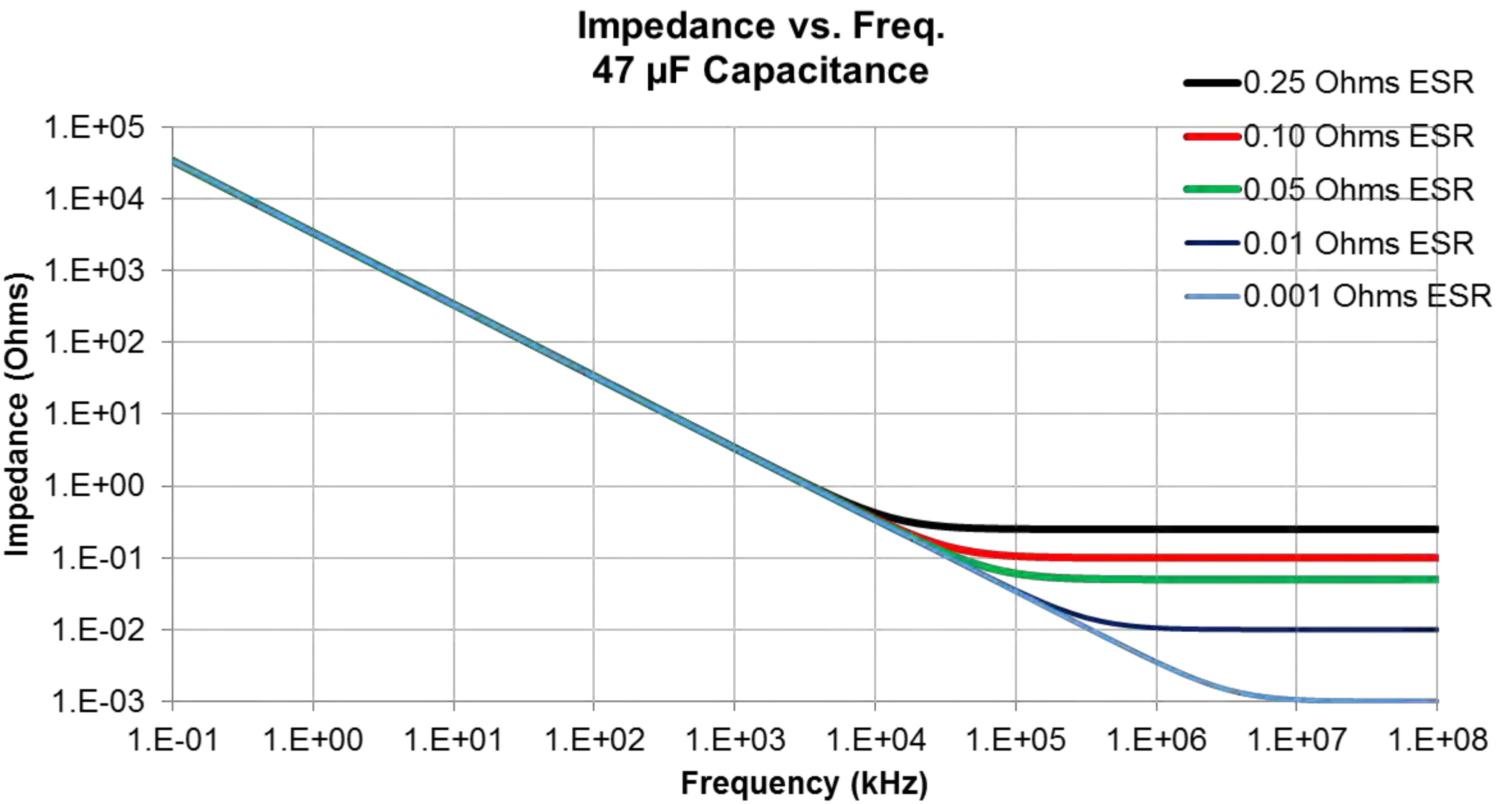
f is frequency (Hertz)

C is capacitance (Farads)

Capacitor with Equivalent Series Resistance



$$|Z| = \sqrt{X_C^{\,2} + ESR^2}$$

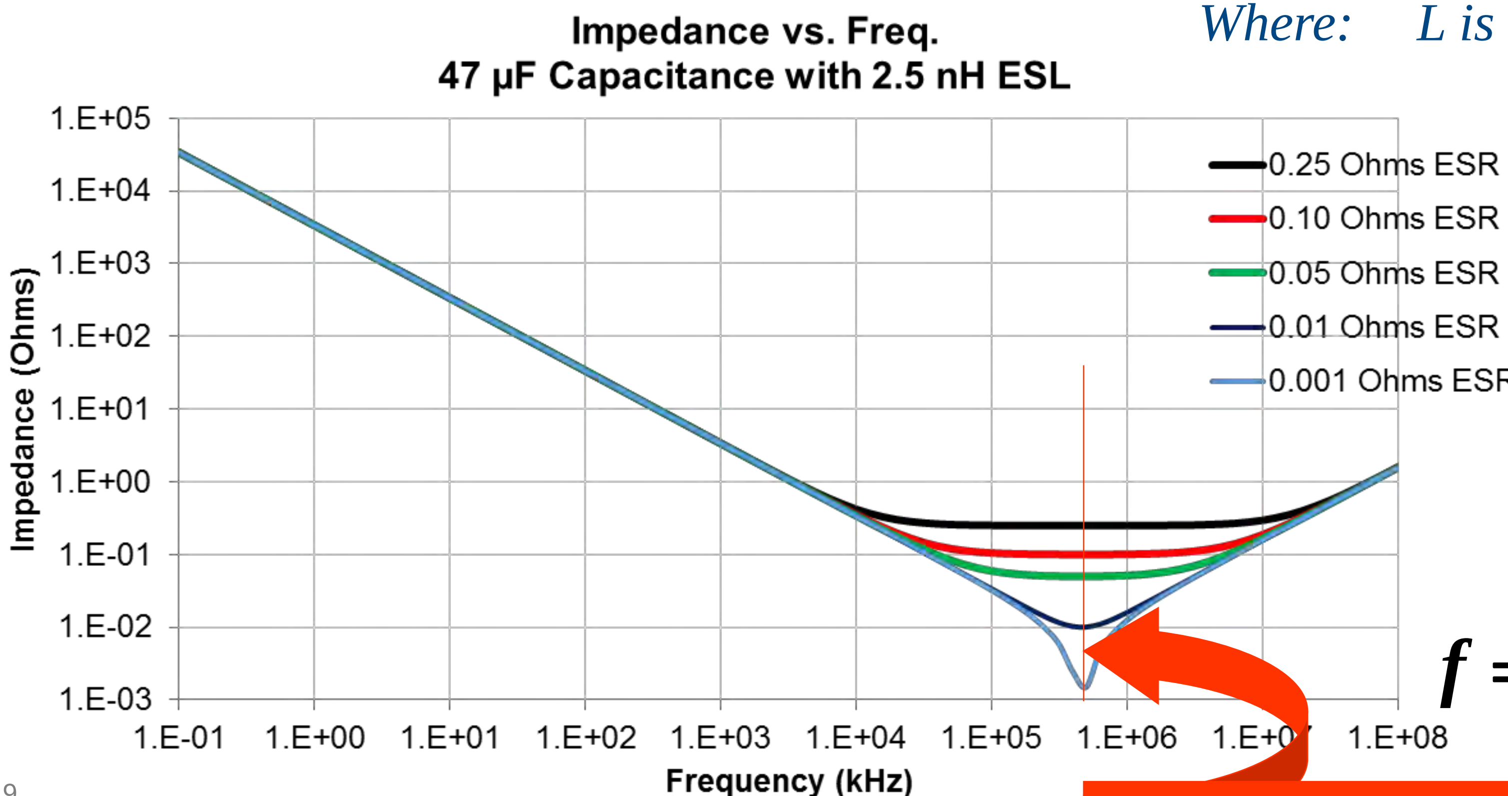


Capacitor with Equivalent Series Resistance and Inductance

$$|Z| = \sqrt{\left(|X_C| - |X_L|\right)^2 + |ESR|^2}$$

$$X_L = 2\pi f L$$

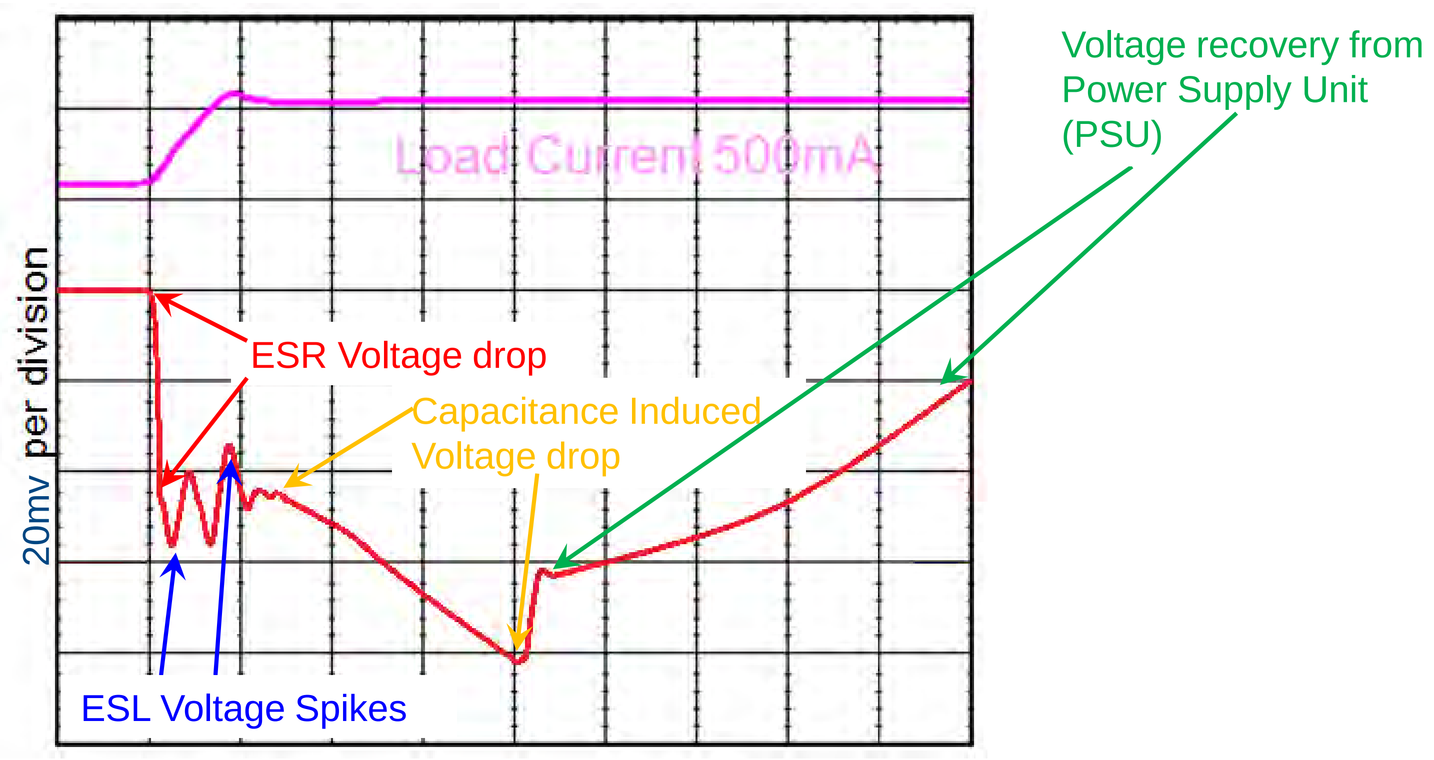
Where: L is in Henries



$$f = \frac{1}{2\pi\sqrt{LC}}$$

self-resonant frequency.

Transient Response
(C+ESR+ESL)



Capacitance: 200 µF
ESR: 33 mΩ
ESL: 100 nH

Electronic Components

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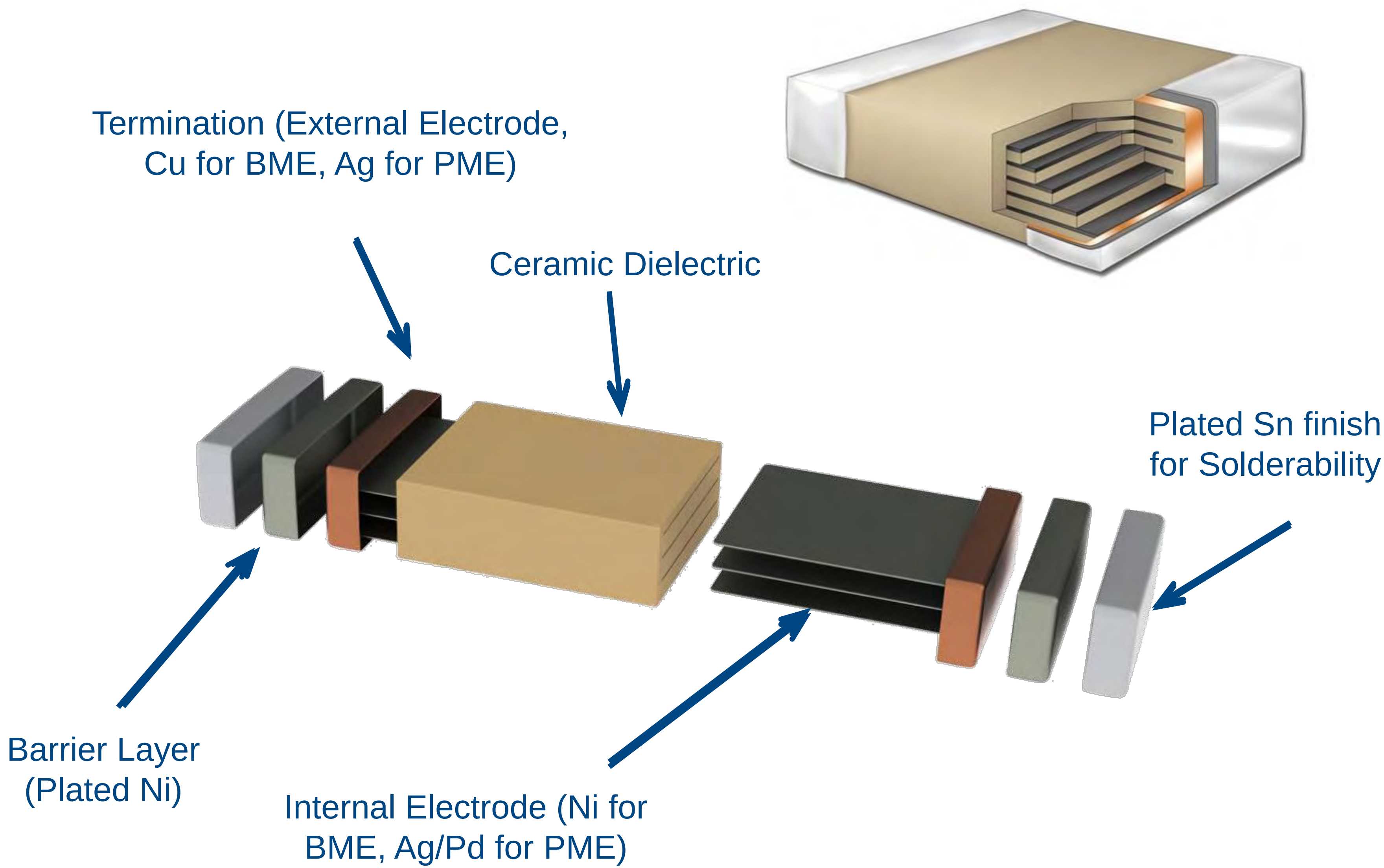
Ceramic Capacitors (MLCCs)

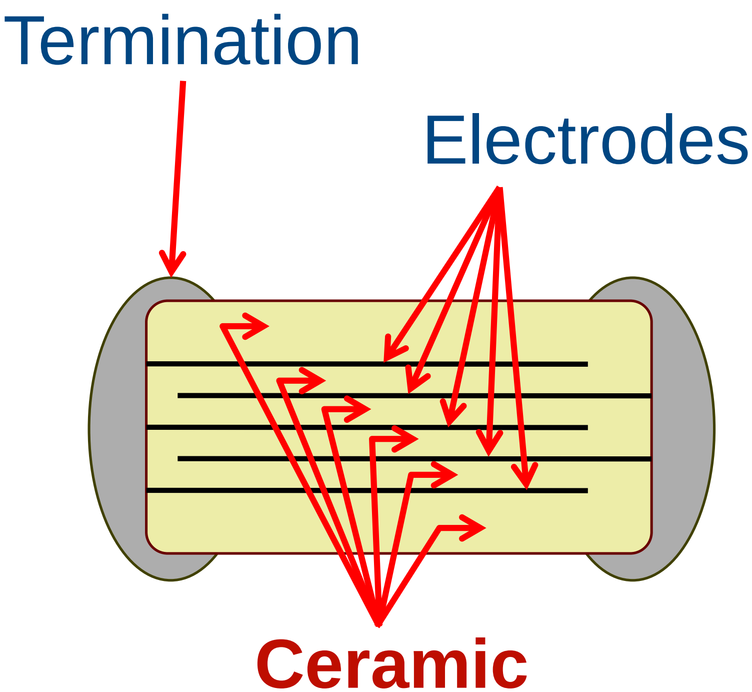
Design and Characteristics

Multilayer Ceramic Capacitor (MLCC)

Typical Construction



Ceramic Capacitance Structure



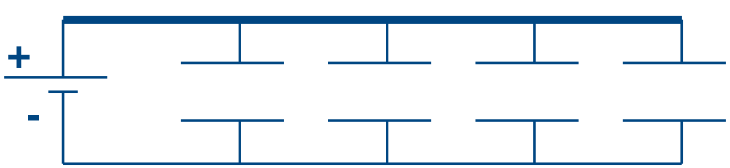
C = Design Capacitance

K = Dielectric Constant

A = Overlap Area

d = Ceramic Thickness

n = Number of Electrodes



Capacitances in parallel are additive

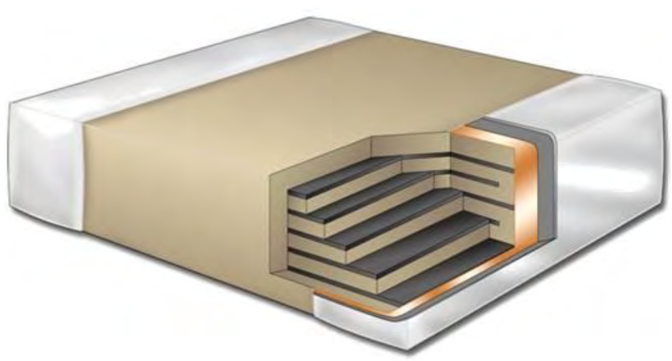
$$C_T = C_1 + C_2 + C_3 + \ldots . C_n$$

$$C = \frac{e_0 K A (n-1)}{d}$$

Dielectric Technology

Commercial & Automotive Grade Dielectric Materials

- **C0G**
  - PME & BME
  - 200^{o}C
- **U2J**
  - Under Development
  - BME
- **X8R**
  - BME
- **X8L**
  - BME
- **X7R**
  - PME & BME
  - 175^{o}C
- **X5R**
  - BME
- **Y5V**
  - BME
- **Z5U**
  - BME

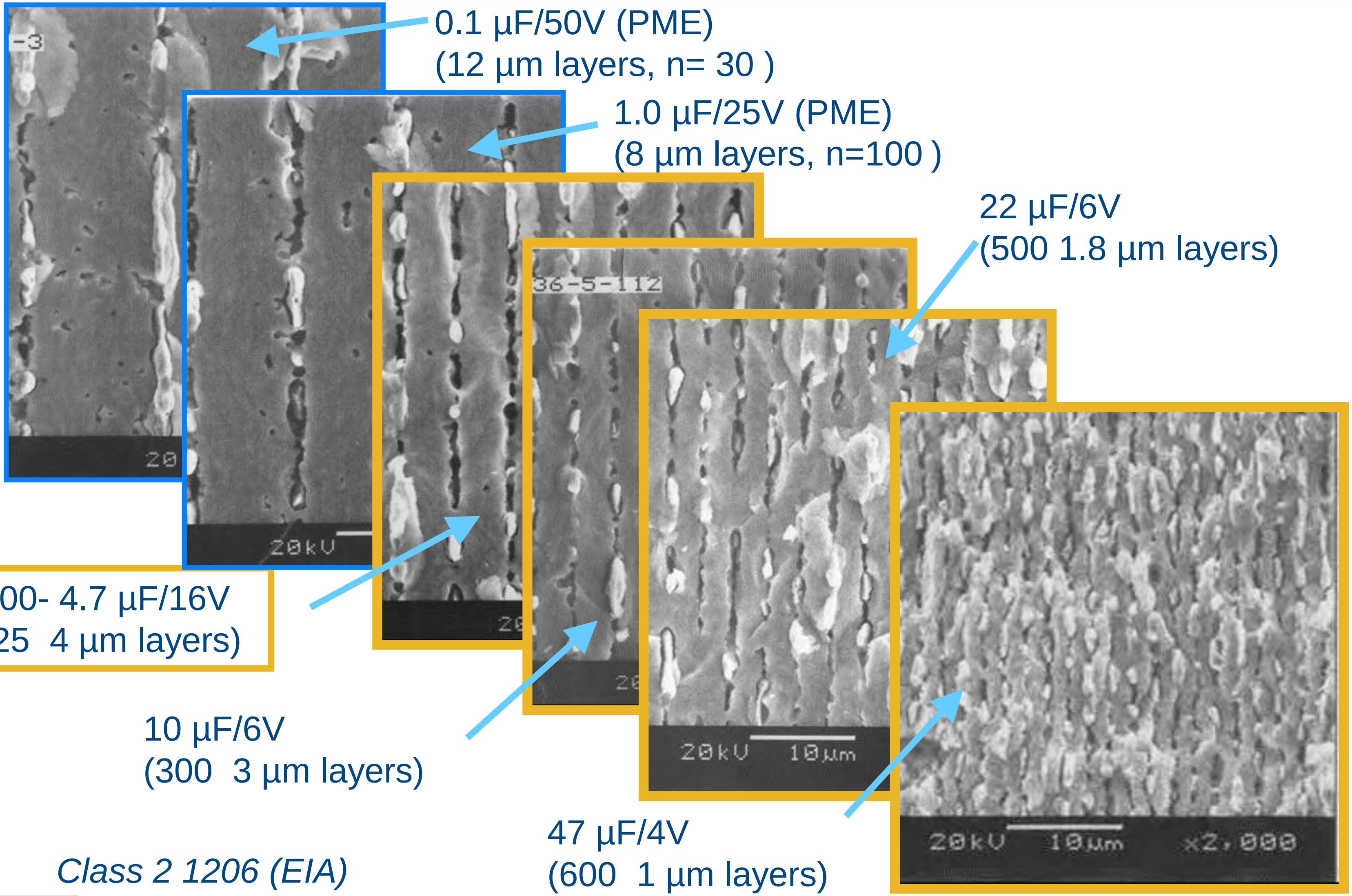


Military & Hi-Rel Dielectric Materials

- **BP**
  - PME
  - C0G @ Rated V
- **BX**
  - PME
  - X7R +15/25% @ Rated V
- **BR**
  - PME
  - X7R & +15/-40% @ Rated V

Trend in BME MLCC Technology:

Dielectric Thickness and Layers Count Progression



0.1 µF/50V (PME)
(12 µm layers, n= 30)

1.0 µF/25V (PME)
(8 µm layers, n=100)

22 µF/6V
(500 1.8 µm layers)

2000- 4.7 µF/16V
(225 4 µm layers)

10 µF/6V
(300 3 µm layers)

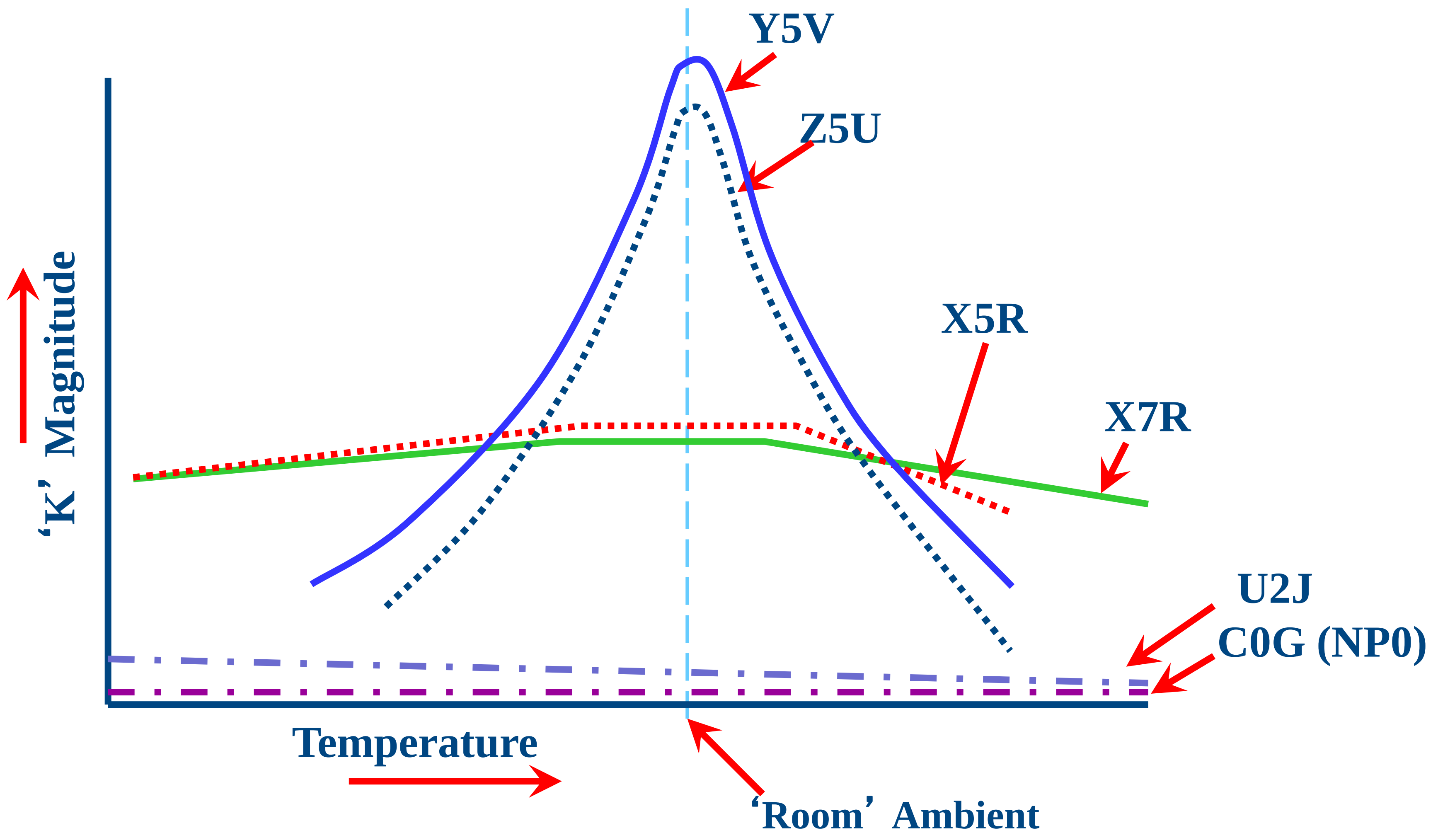
47 µF/4V
(600 1 µm layers)

Class 2 1206 (EIA)

1988 → Today

Characteristics

Relative Capacitance vs. Temperature



Dielectric Classification

Class I (Per EIA – 198)

Class I Dielectrics: (Example: C0G)

Alpha Symbol	Significant Figure of Temp Coefficient ppm/ºC	Numerical Symbol	Multiplier to significant figure	Alpha Symbol	Tolerance of Temp Coefficient ± ppm/ºC
C	0	0	-1	G	30
B	0.3	1	-10	H	60
L	0.8	2	-100	J	120
A	0.9	3	-1000	K	250
M	1.0	4	-10000	L	500
P	1.5	5	+1	M	1000
R	2.2	6	+10	N	2500
S	3.3	7	+100		
T	4.7	8	+1000		
U	7.5	9	+10000		

Temperature Range: -55ºC to +125ºC

C0G provides highest temperature stability

Dielectric Classification

Class II and III (per EIA-198)

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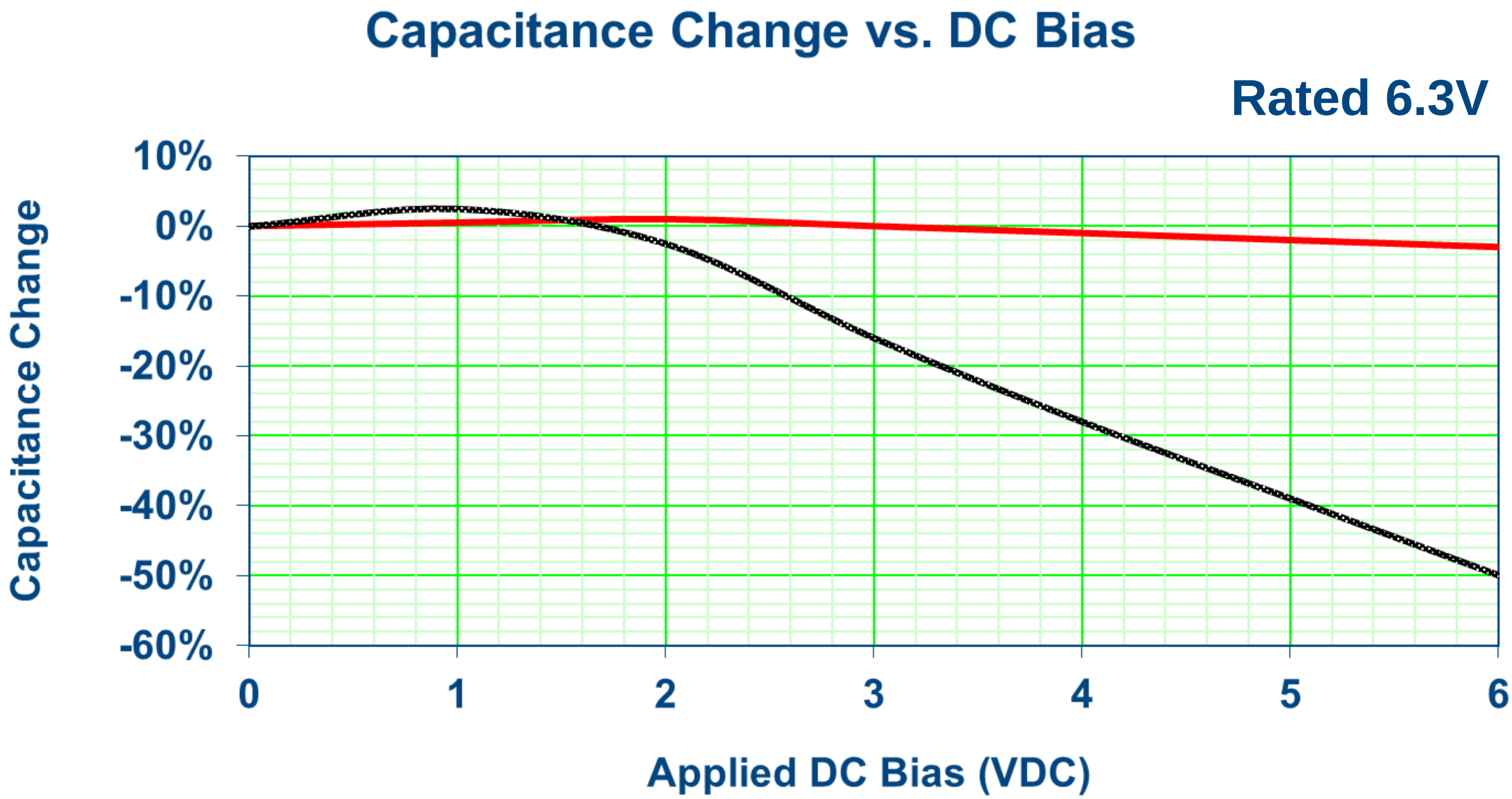
Alpha Symbol	Low Temperature (ºC)	Numerical Symbol	High Temperature (ºC)	Alpha Symbol	Max cap change over temp. range (%)	
Z	+10	2	+45	A	±1.0	CLASS II
Y	-30	4	+65	B	±1.5	CLASS II
X	-55	5	+85	C	±2.2	CLASS II
		6	+105	D	±3.3	CLASS II
		7	+125	E	±4.7	CLASS II
		8	+150	F	±7.5	CLASS II
		9	+200	P	±10	CLASS II
				R	±15	CLASS II
				S	±22	CLASS II
				* L	+15 to - 40	CLASS II
				T	+22 to - 33	CLASS III
				U	+22 to - 56	CLASS III
				V	+22 to - 82	CLASS III

* Industry Classification (Non EIA-198)

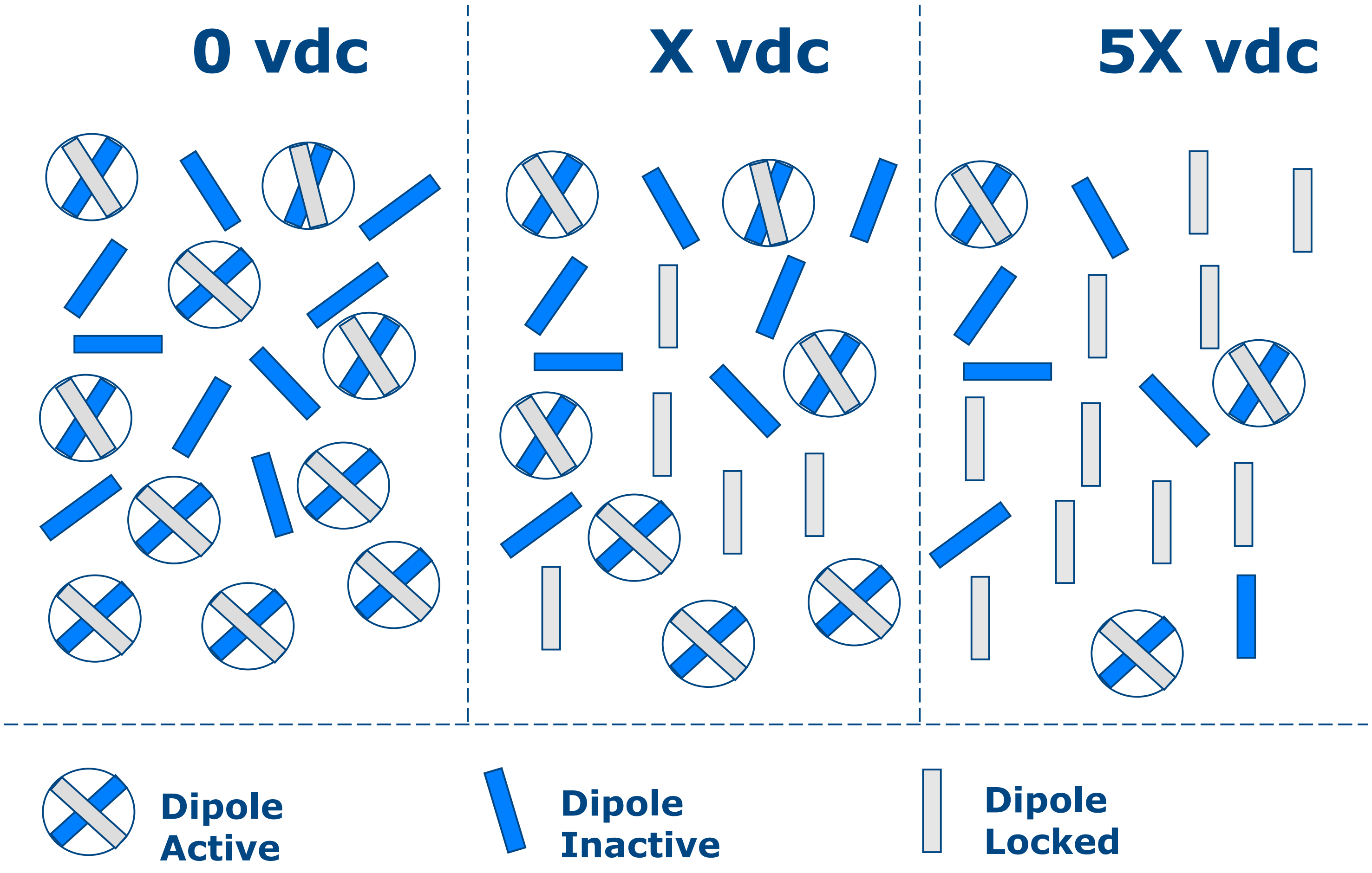
Voltage Coefficient (Class II and III)

1210 vs 0805, X7R, 10uF, 6.3V



Voltage Coefficient (Class II and III)

DC Bias – Loss of Dipoles

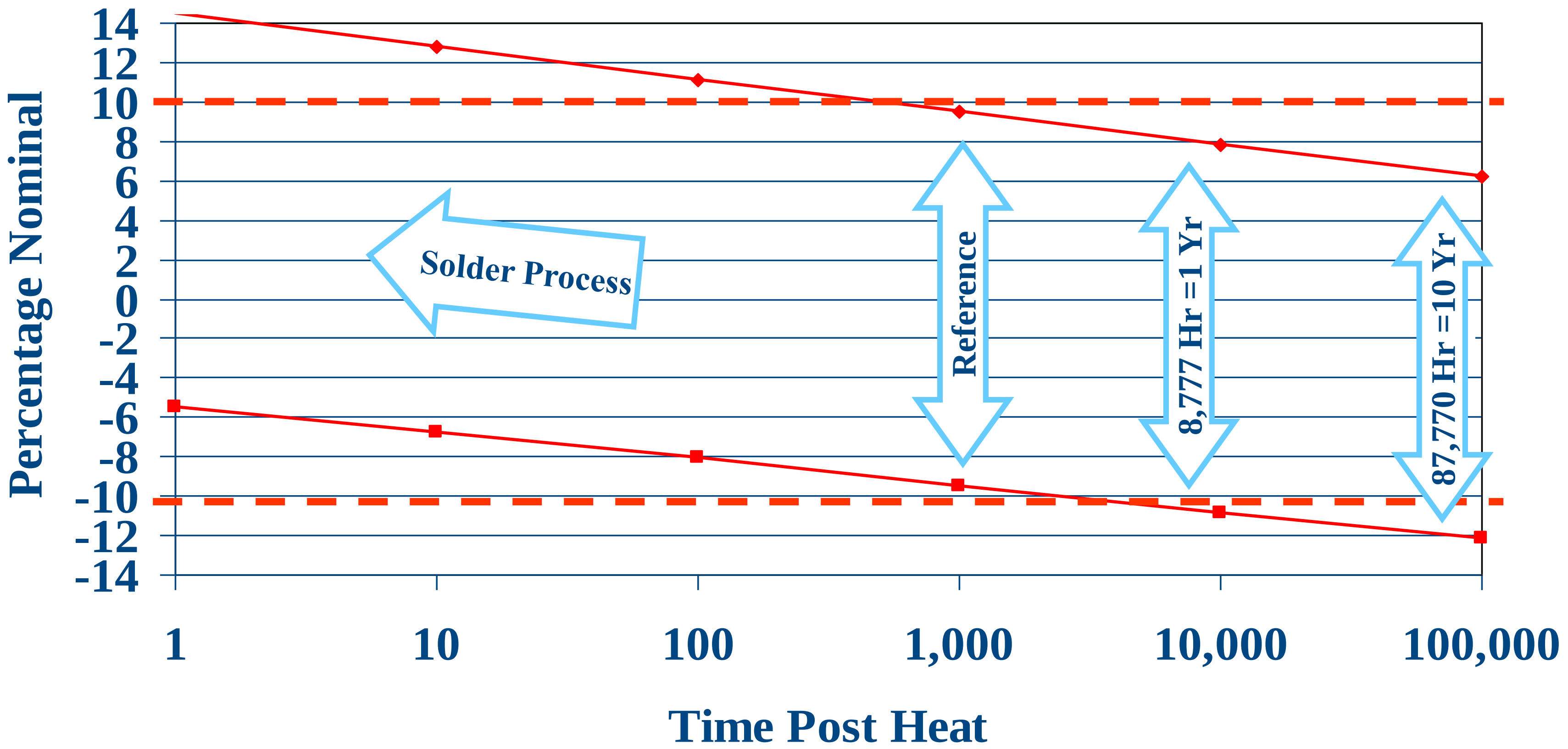


Electric field locks dipoles

Locked dipoles do NOT contribute to capacitance

X7R Aging Rate

3% per Decade Hour (Limit)



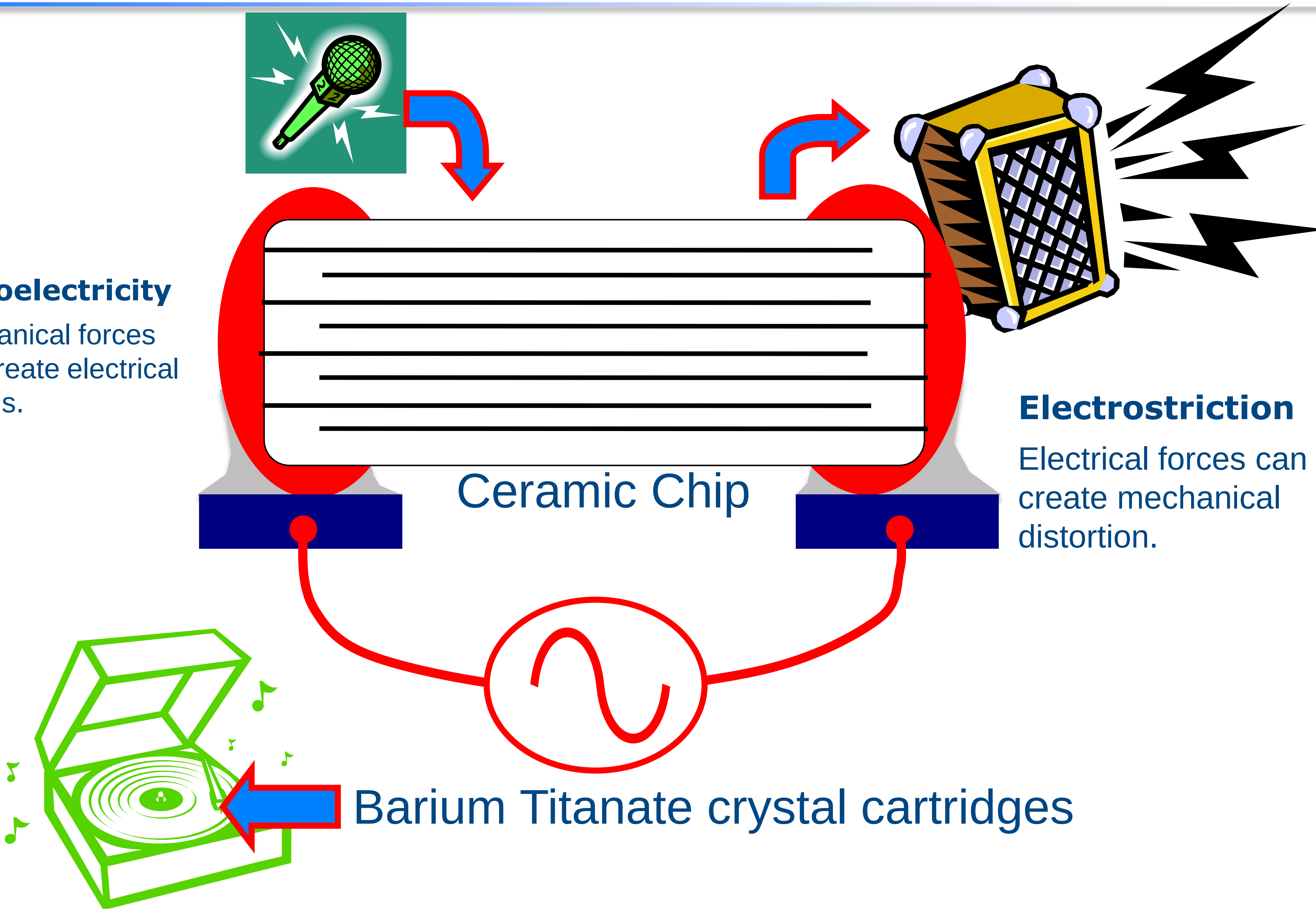
https://ec.kemet.com/design-tools/aging-calculator-for-ceramics

Piezoelectric Noise

Class II and III Only

Piezoelectricity

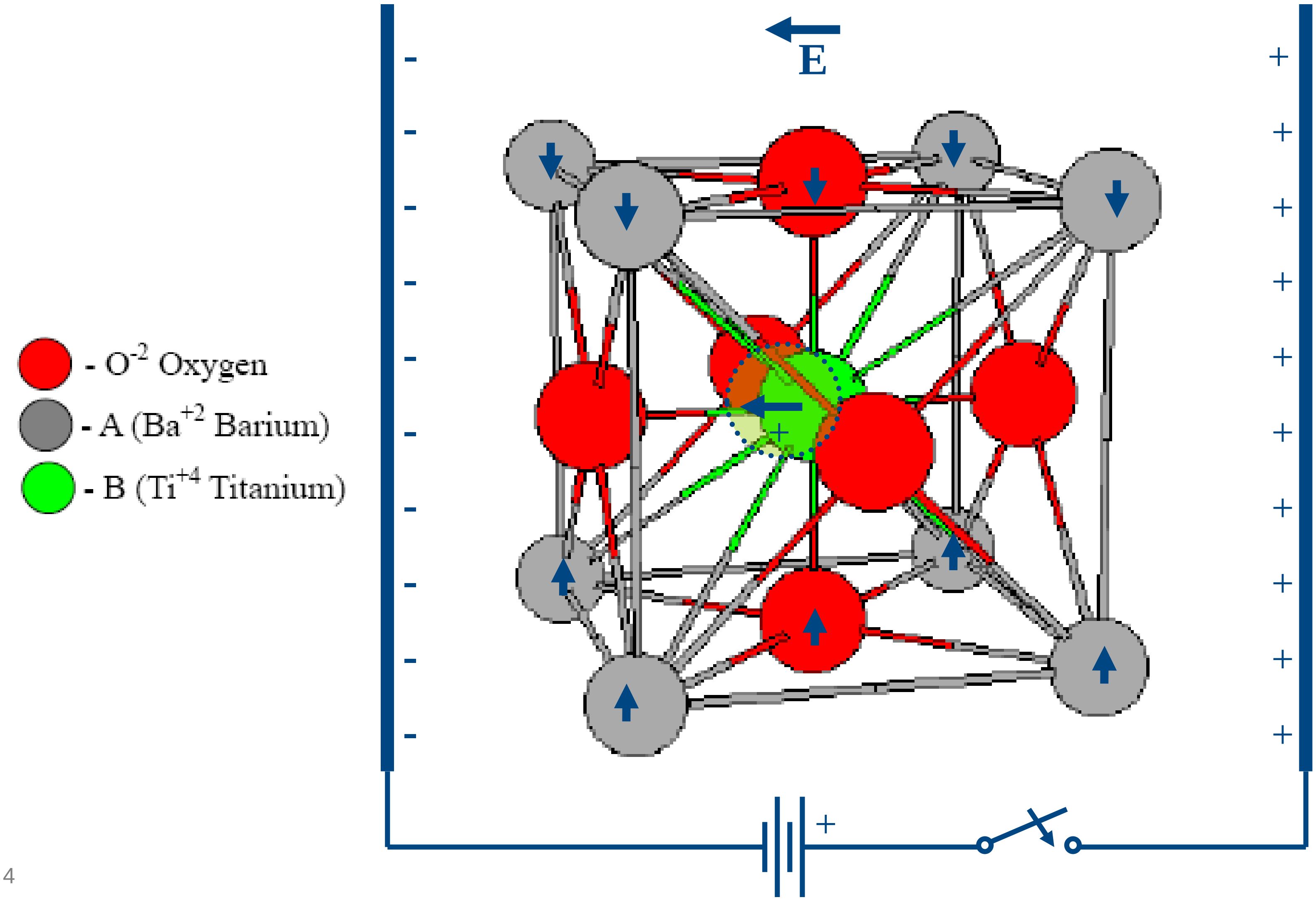
Mechanical forces can create electrical signals.



Electrostriction

Electrical forces can create mechanical distortion.

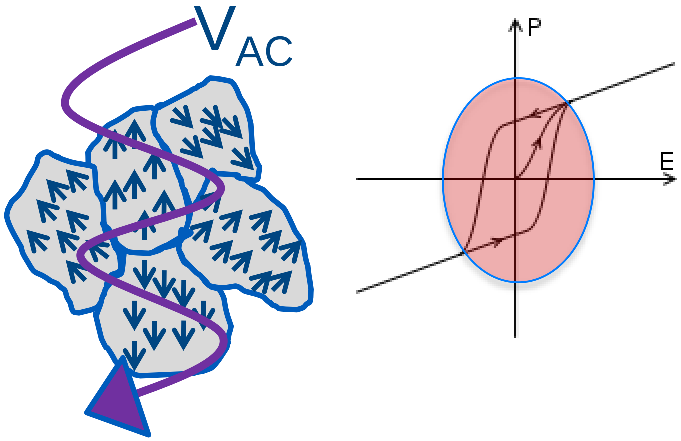
Electrostrictive Behavior in Barium Titanate



AC Coupling and Signal Distortion

X7R vs C0G

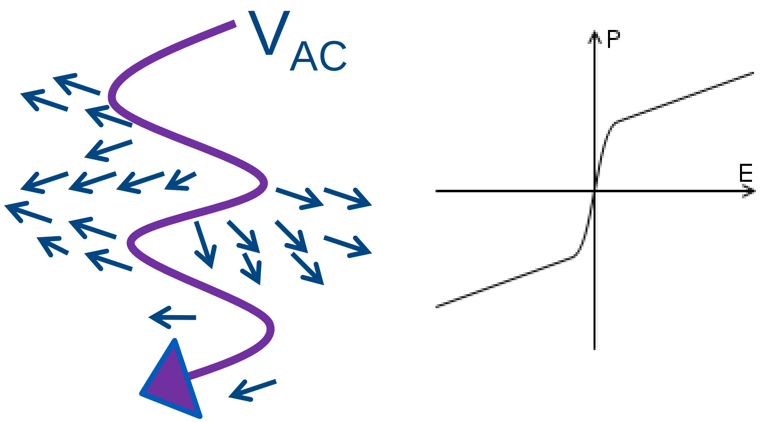
Class 2 $BaTiO_3$
Ferroelectric



Ferroelectric dipoles in *domains* align with the AC Field

Domain wall heating &
Signal distortion

Class 1 $CaZrO_3$
Paraelectric



Paraelectric dipoles align with AC field

No domains, so
No Domain wall heating &
Reduced signal distortion

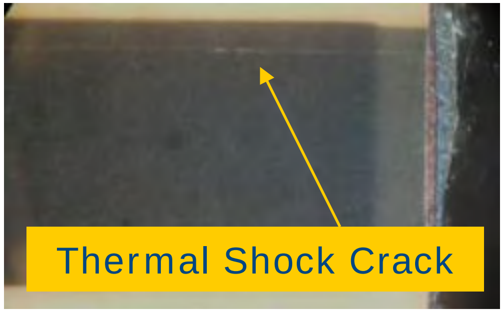
Typical Crack Signatures

MLCC Cross-Sections

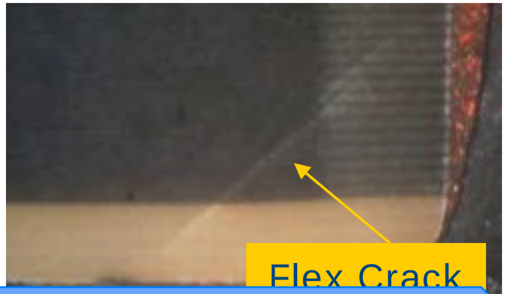
The major sources MLCC of cracks are:

– Mechanical damage (impact)
  - Aggressive pick and place
  - Physical mishandling

– Thermal shock (parallel plate crack)
  - Extreme temperature cycling
  - Hand soldering
    - *Do not touch electrodes while hand soldering!*

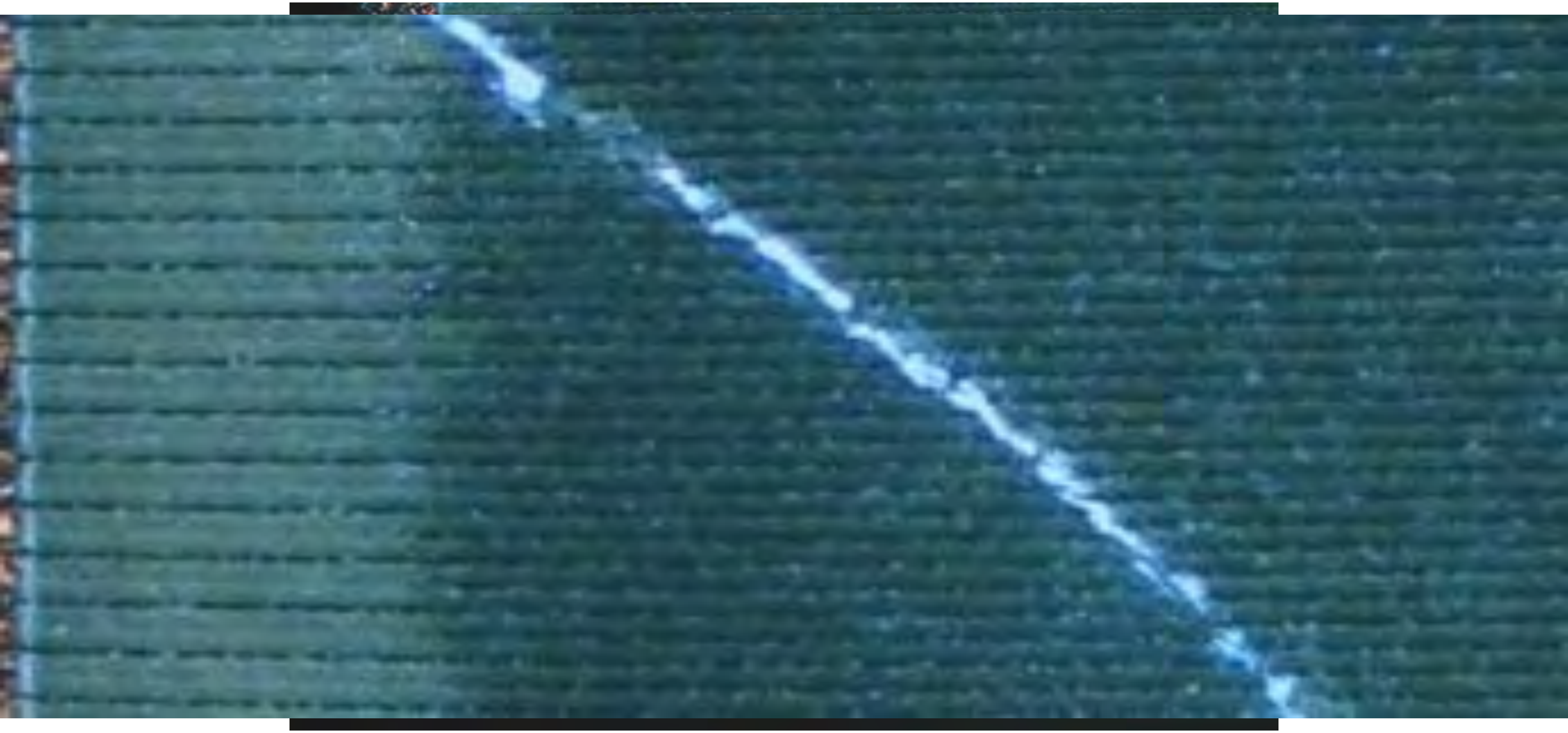


– Flex or Bend stress
  - Occurs after mounted to board
  - Common for larger chips (>0805)



Failure is **not always immediate**!
Failure mode is **not always deterministic**!

Flex Cracks



https://ec.kemet.com/q-and-a/what-is-failure-mode-for-ceramic-capacitors

https://ec.kemet.com/knowledge/flexible-termination-reliability-in-harsh-environments

Polymer (Tantalum) Capacitors

Design and Characteristics

Common Myths

Myth 1: The World Is Running Out Of Tantalum

Electronic Components KEMET CHARGED.

USGS science for a changing world

US Geological Survey Fact Sheet 2014-3054
June-2014

USGS Mineral Resources Program

Niobium and Tantalum—Indispensable Twins

41 Nb [Kr]5s[1]4d[4] 92.91

73 Ta [Xe]6s[2]4f[14]5d[3] 180.9

The Future of Niobium and Tantalum: Worldwide Supply and Demand

Estimated global reserves and resources of niobium and tantalum are large and more than sufficient to meet global demand for the foreseeable future, possibly the next 500 years. Therefore, geologic availability does not appear to be a major concern for the supply of niobium or tantalum. Brazil, Canada, and Australia are the leading global producers of niobium and tantalum mineral concentrates. Brazil produces the greatest amount of niobium mineral concentrates (~90 percent), while Australia and Brazil together lead in the production of tantalum mineral concentrates. A number of African countries—Burundi, Democratic Republic of Congo, Ethiopia, Mozambique, Nigeria, Rwanda, Uganda—mine for tantalum minerals (such as columbite-tantalite, also called coltan) through artisanal mining or are establishing mining operations. Primary production of niobium or tantalum in the United States has not been reported since the late 1950's; therefore, the United States has to meet its current and expected future needs by importing primary mineral concentrates and alloys, and by recovering them from foreign and domestic alloy scrap.

High-purity niobium crystals, electrolytic made, as well as a high-purity 1 cubic centimeter anodized niobium cube for comparison (photograph from Wikipedia).

Expected shortages of metals within the next 50-100 years include Copper, Gold, Silver, Indium, Platinum, Zinc and Lead.

Myth 2: Tantalum Is Only For Capacitor Production

USGS science for a changing world

US Geological Survey Fact Sheet 2014-3054
June-2014

USGS Mineral Resources Program

41 Nb [Kr]5s[1]4d[4] 92.91 — 73 Ta [Xe]6s[2]4f[14]5d[3] 180.9

Niobium and Tantalum—Indispensable Twins

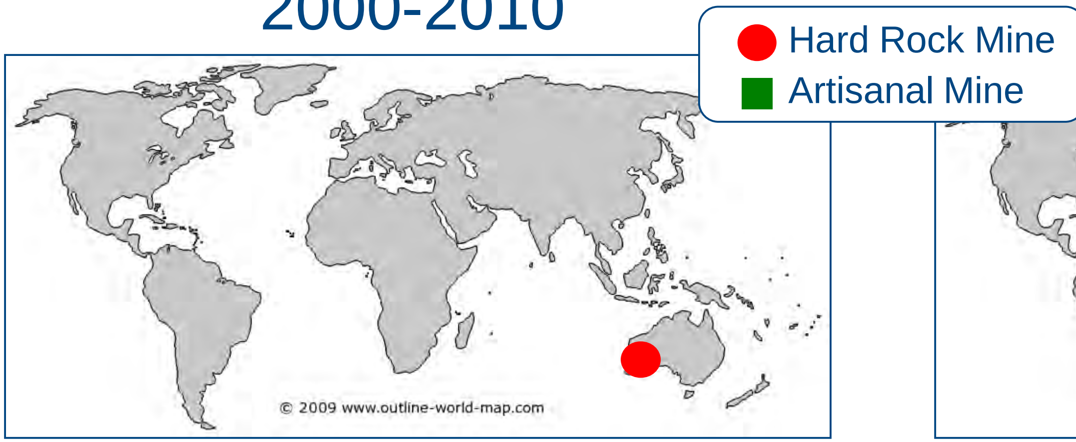
How Do We Use Niobium and Tantalum?

Tantalum has a unique ability to store and release energy, which is why the electronics industry consumes more than one-half of tantalum production. Tantalum-based components can be exceptionally small, and other elements cannot serve as substitutes without degrading the performance of electronic devices. As a result, tantalum is used in components for items as ubiquitous as cell phones, hearing aids, and hard drives. Tantalum's low mechanical strength and high biocompatibility allow it to coat stronger substrates, like stainless steel, for medical applications. It is used for blood vessel support stents, plates, bone replacements, and suture clips and wire. In the chemical industry, tantalum's corrosion resistance makes it useful as a lining for pipes, tanks, and vessels. Tantalum oxide can increase the refractive index of lens glass, while the hardness of tantalum carbide makes it an ideal component in the manufacture of cutting tools.

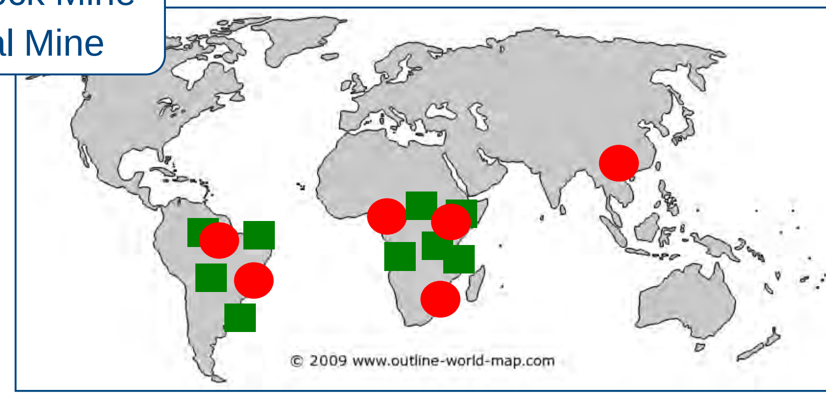
Only half of the world's annual Tantalum output is used in capacitor production

Myth 3: World Demand For Tantalum Frequently Exceeds Available Supply

2000-2010



2010-Present



- Single source for ore
- Expensive hard rock operation
- When market price dropped below operating cost, the mine discontinued operations until metal prices increased.

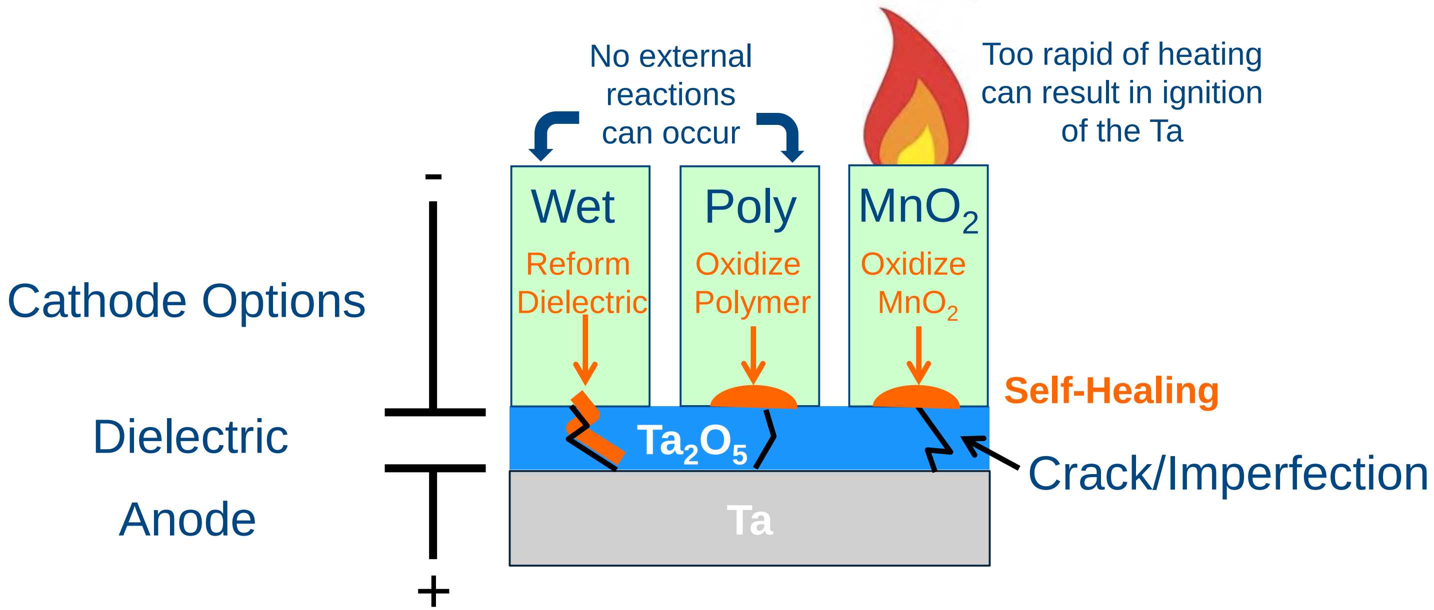
- Multiple sources for ore
- Mix of artisanal (open pit) and hard rock operations.
- Multiple regions of the world.
- Mix of regions and mines result in a competitive market place.

Most of the shortages experienced in the industry were artificially created. In recent years, capacitor manufacturers have established broader supply chain networks to prevent this from occurring.

Myth 4: Tantalum Capacitors Do Not Possess a Safe Failure Mode

Tantalum Capacitor Classes:

- Wet Cathodes
- Solid Polymer Cathodes
- Solid MnO_2 Cathodes



The cause of the undesirable failure mode is the MnO_2 cathode. But users often define it as "Tantalum".

Myth 5: Tantalum Capacitors Are Only Used In High End Applications

While Ta caps are not as frequently used as ceramic or aluminum, they are widely used in our daily lives.

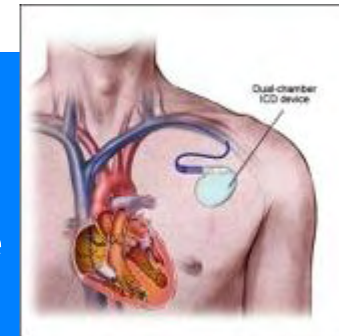
It is likely that you carry 10 to 50 Tantalum capacitors with you everyday in your laptops, tablets, and smart phones.

Design

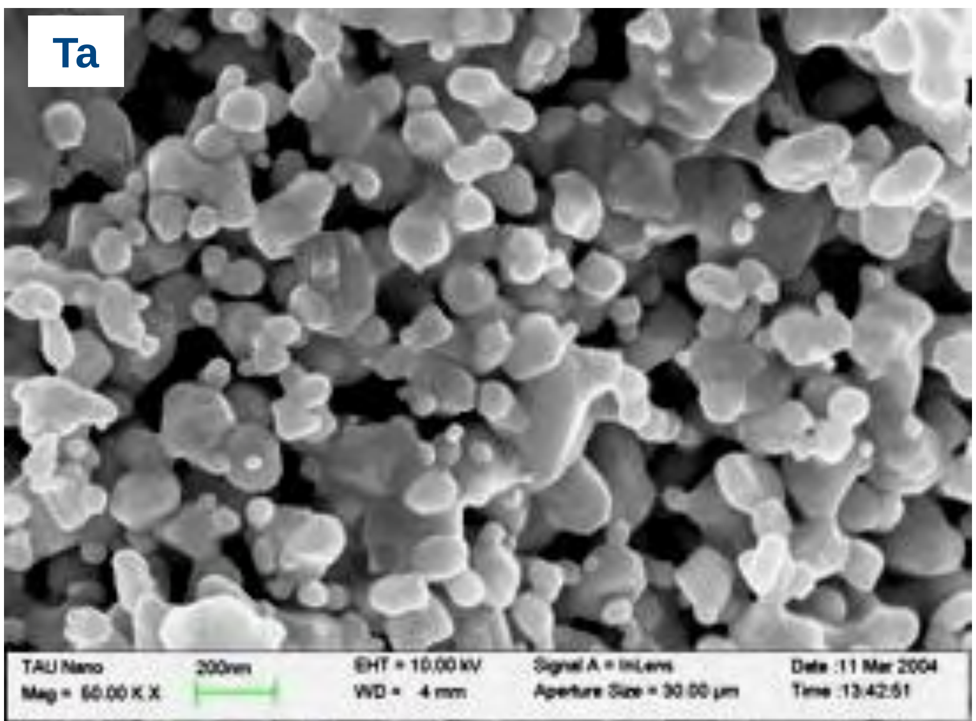
Why Use Tantalum?

- Stable C (No Temp or Bias Effects), DCL (t)
- Reliable (Decreasing FR)
- Long Life (Exceeds Expected Life of All Hardware)
- Most Volumetrically Efficient (CV/cc, E/cc)

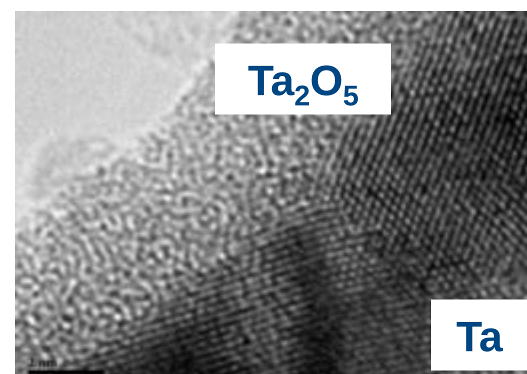
Military
Space
Medical
Automotive
Computers
Telecom



SEM of a Sintered Ta Anode



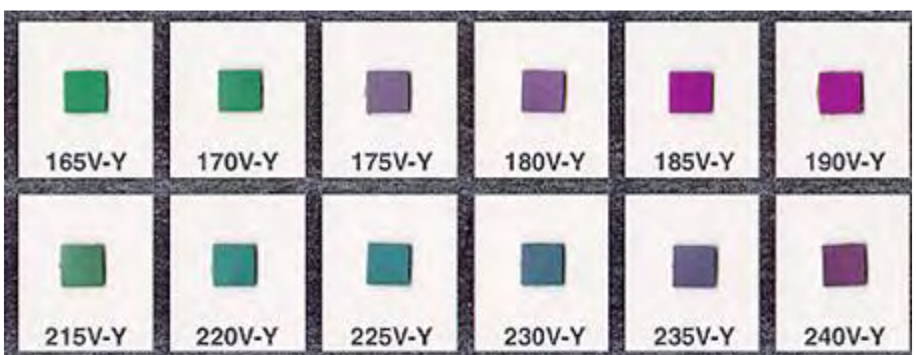
Ta Oxide Dielectric



Dielectric: Tantalum Pentoxide Ta_20_5

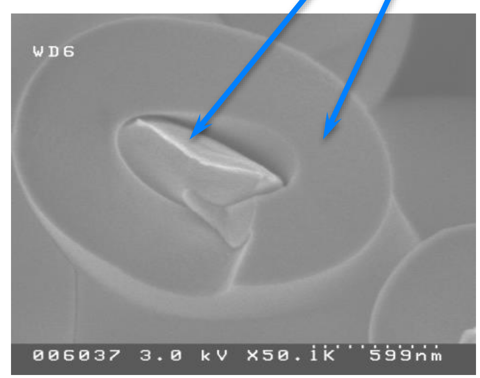
- Critical Characteristics
  - Dielectric constant
    - 27.7
  - Dielectric breakdown
    - VBDV 470 volt/mm)
  - Dielectric thickness:
    - 2.0 nm/volt
  - Resistant to chemical attack

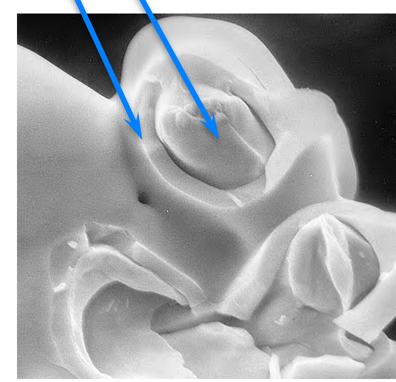
	Dielectric Thickness (nm)	
V_R	**Ta**	**MLCC**
2	20.7	600
4	27.6	600
6	36.8	600



Tantalum

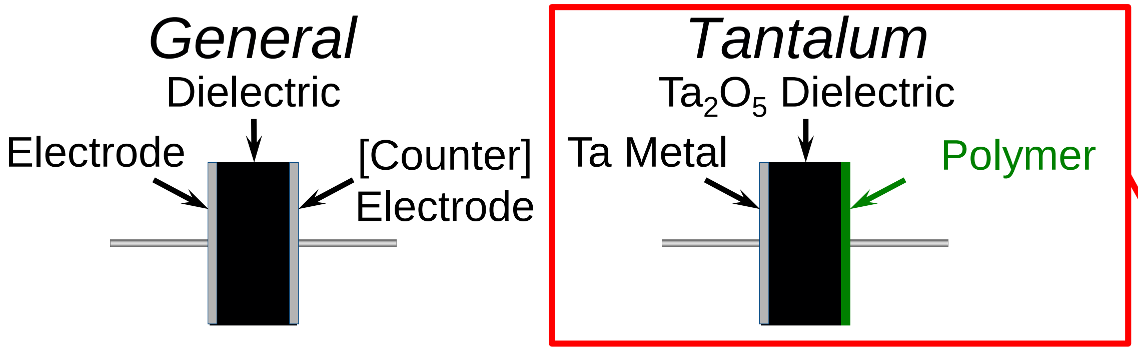
Ta_2O_5



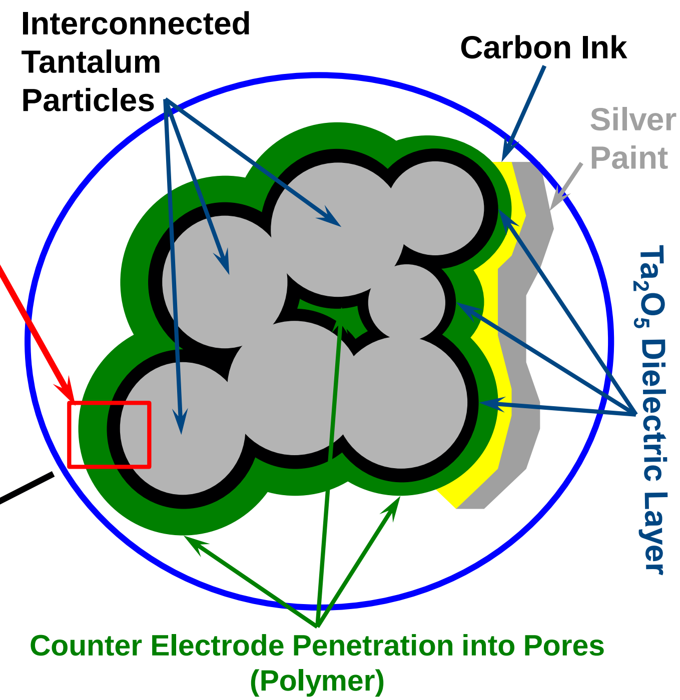


Fractured Sintered Anodes With Dielectric Already Formed

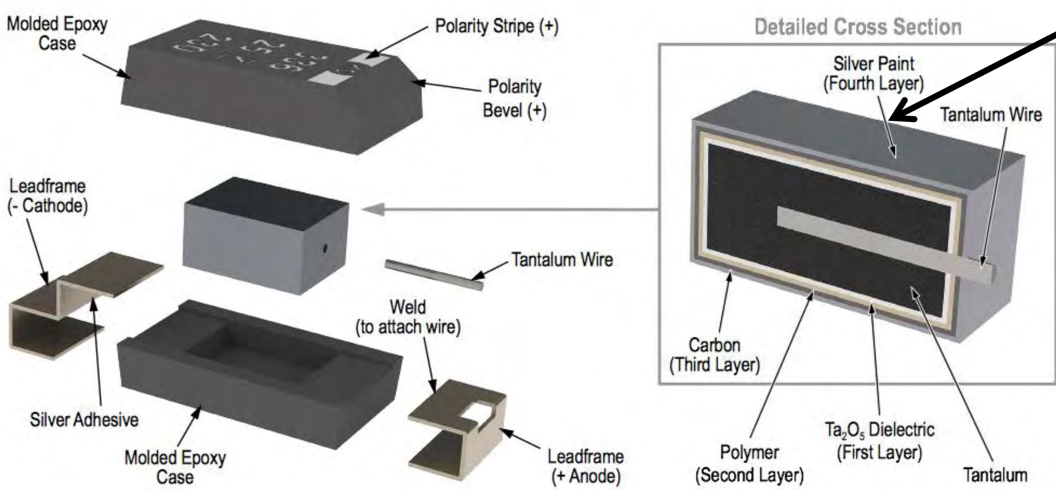
Polymer Construction

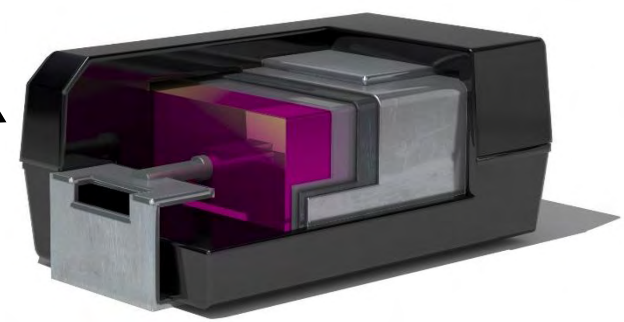


Ta Caps have a 3-D structure

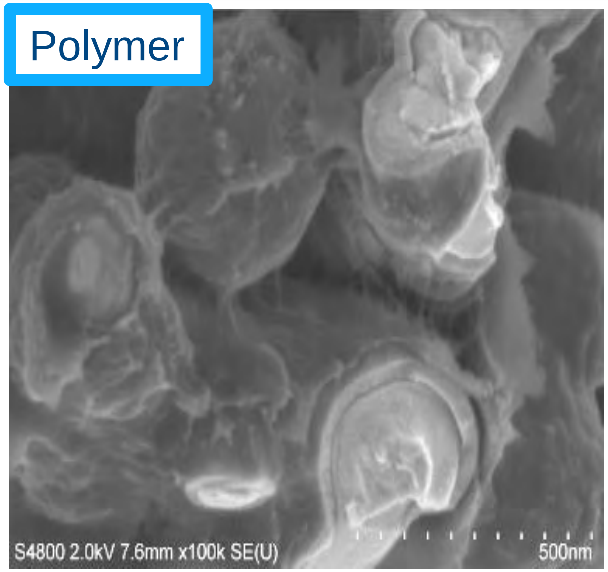


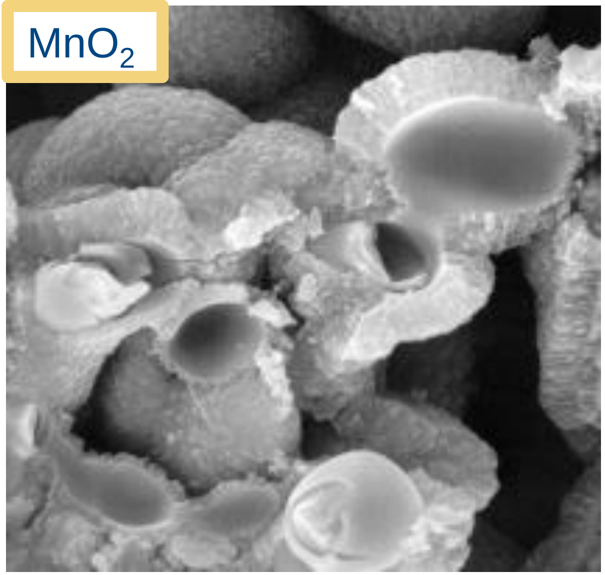
KO-CAP Construction





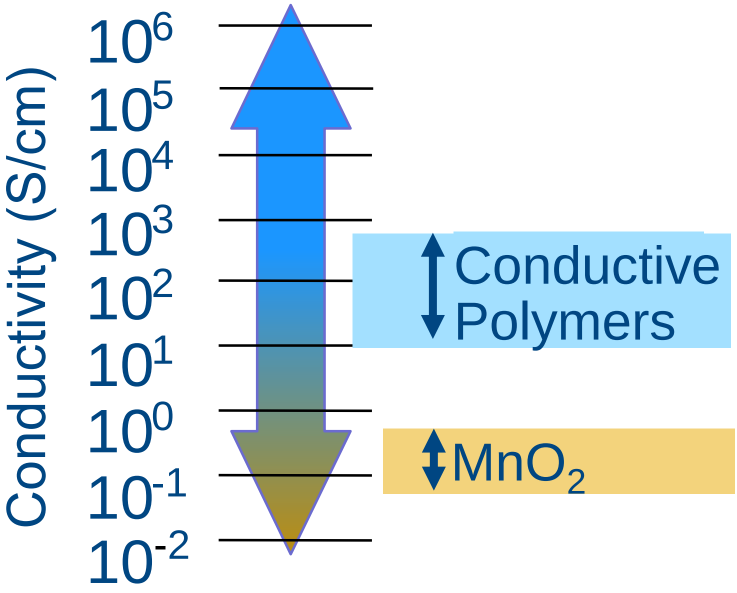
Polymer Cathode





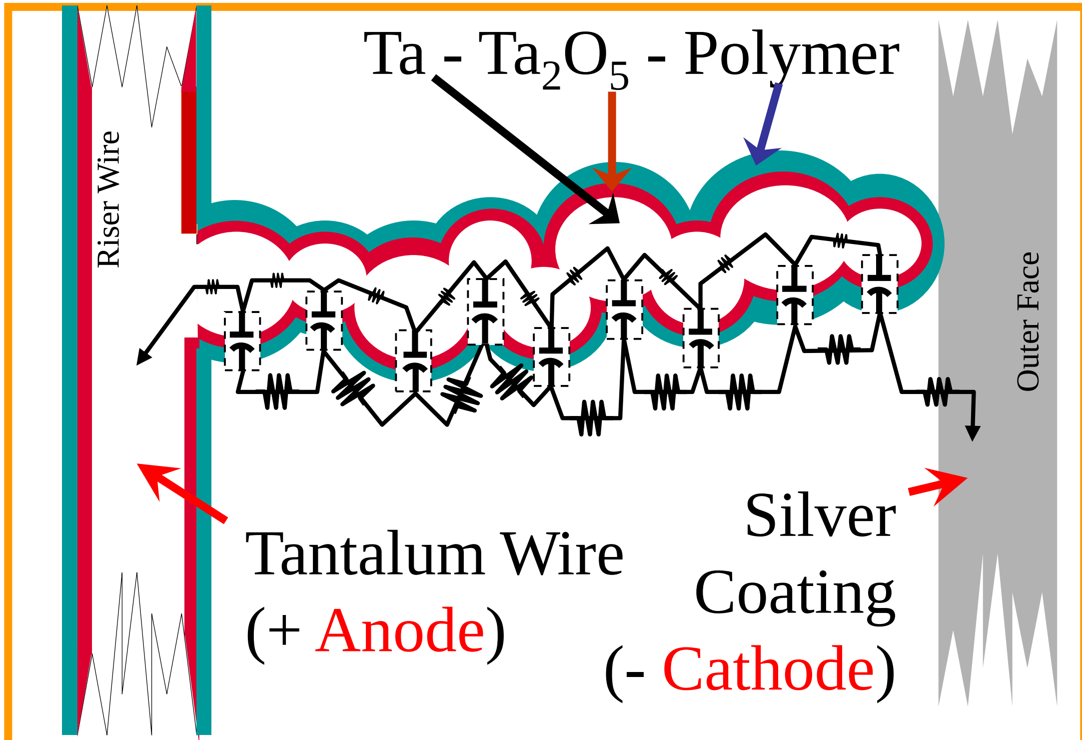
Cathode forms the negative connection:

- Polymer is an intrinsically conductive polymer
- MnO_2 is manganese dioxide

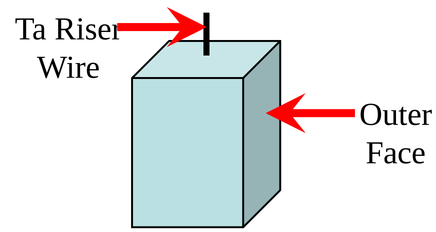


Characteristics

RC-Ladder Effect



RC-Ladder Effects



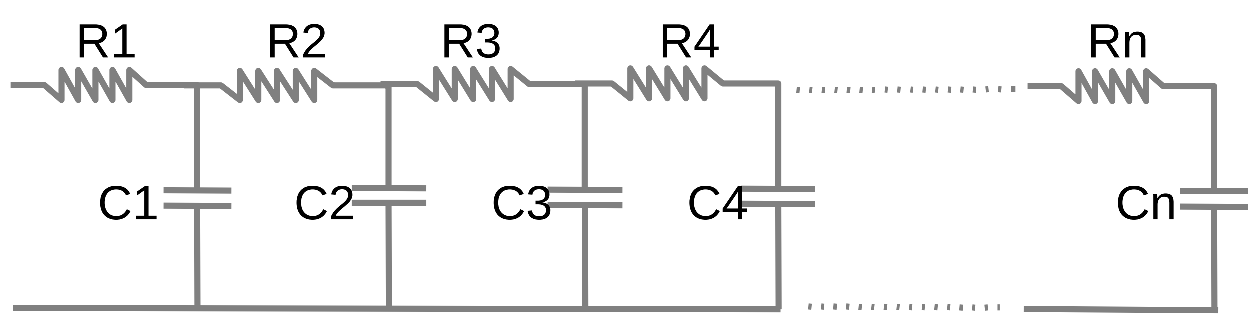
$tc1 = C1 \times R1$

$tc2 = C2 \times (R1+R2)$

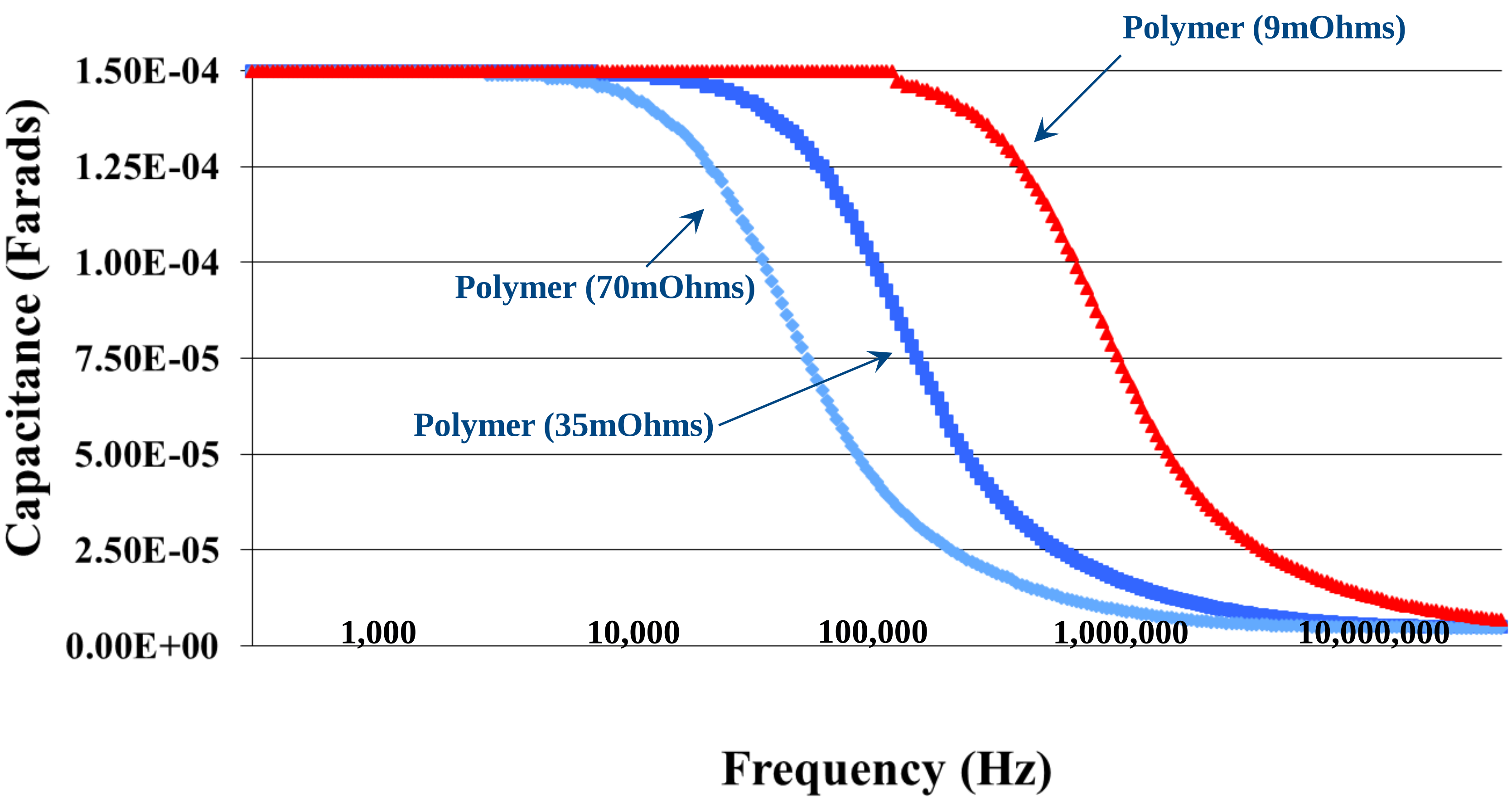
$tc3 = C3 \times (R1+R2+R3)$

$tcn = Cn \times (R1+R2+R3...+Rn)$

RC-Ladder effects are factored by both capacitance and resistance.



Capacitance vs Frequency



Polymers are commonly used in applications of up to 1MHz.
Applications exceeding 1MHz typical call for MLCC's

Voltage Derating Guidelines

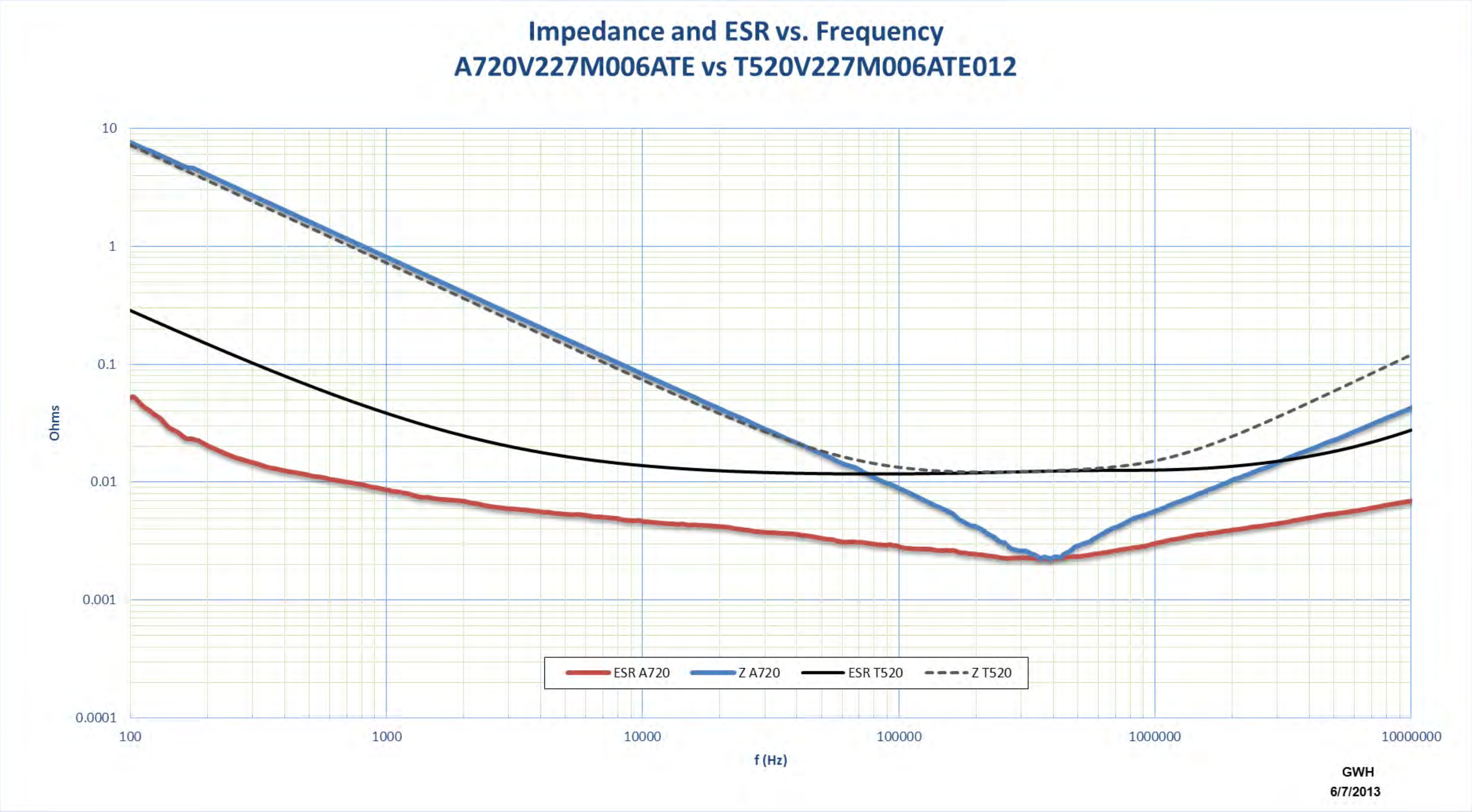
	$Ta\text{-}MnO_2$	Poly KO $V_R>10VDC$	Poly KO $V_R\leq10VDC$	Alum-Poly AO
100 PPM FR % V_{Rated}	68%	126%	197%	235%
@50% V_{Rated} FR(PPM)	9	0	0	0
@80% V_{Rated} FR(PPM)	458	4	1	0
@90% V_{Rated} FR(PPM)	1700	12	2	0
@100% V_{Rated} FR(PPM)	6310	35	8	0
Leakage Limit	0.01CV	0.1CV	0.1CV	0.04-0.06CV

- Typical derating guidelines:
  - Tantalum MnO_2: 50%
  - Polymer KO: 20%(>10V), 10% (≤10V)
  - Aluminum Polymer: 0%
- Temperature Ratings:
  - Tantalum MnO_2: 125ºC up to 230ºC
  - Polymer KO: 105ºC - 125ºC
  - Aluminum Polymer Gen I: 125ºC
  - AO Gen II: 105ºC - 125ºC(future)
  - MLCC (X5R): 85ºC

ESR and Impedance vs. Frequency

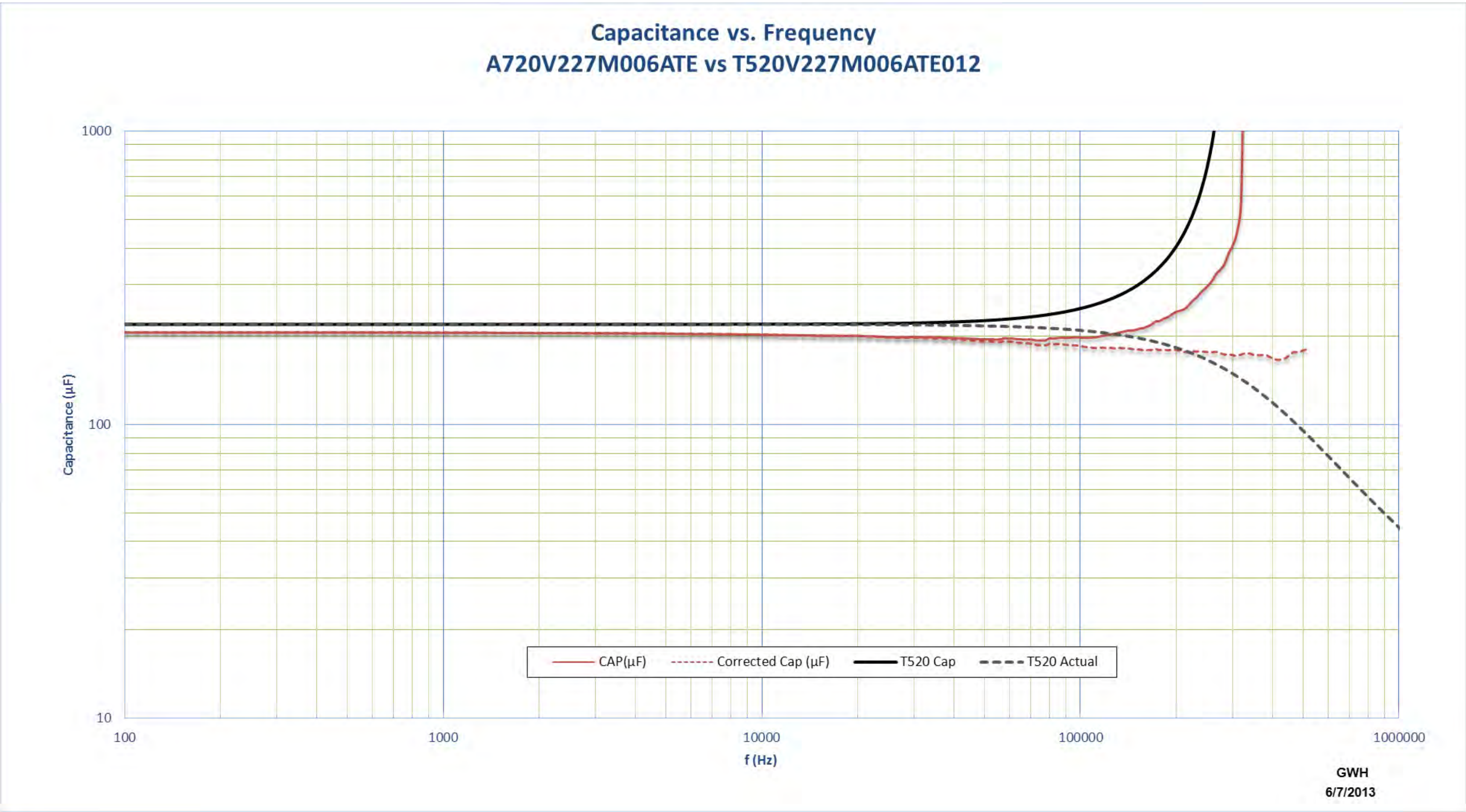
AO Gen II vs. TA Polymer

Electronic Components KEMET CHARGED.



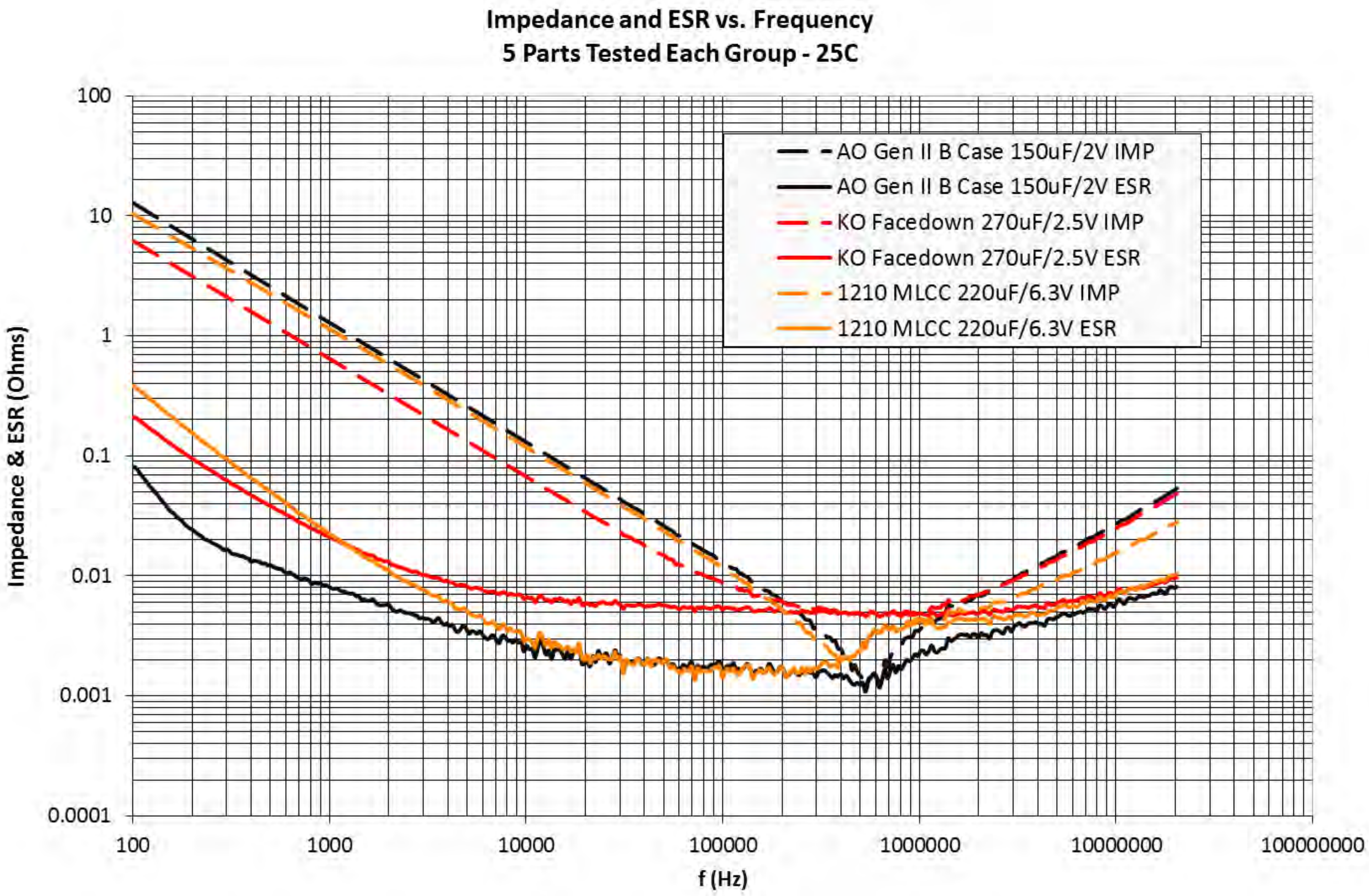
Capacitance vs. Frequency

AO Gen II vs. TA Polymer



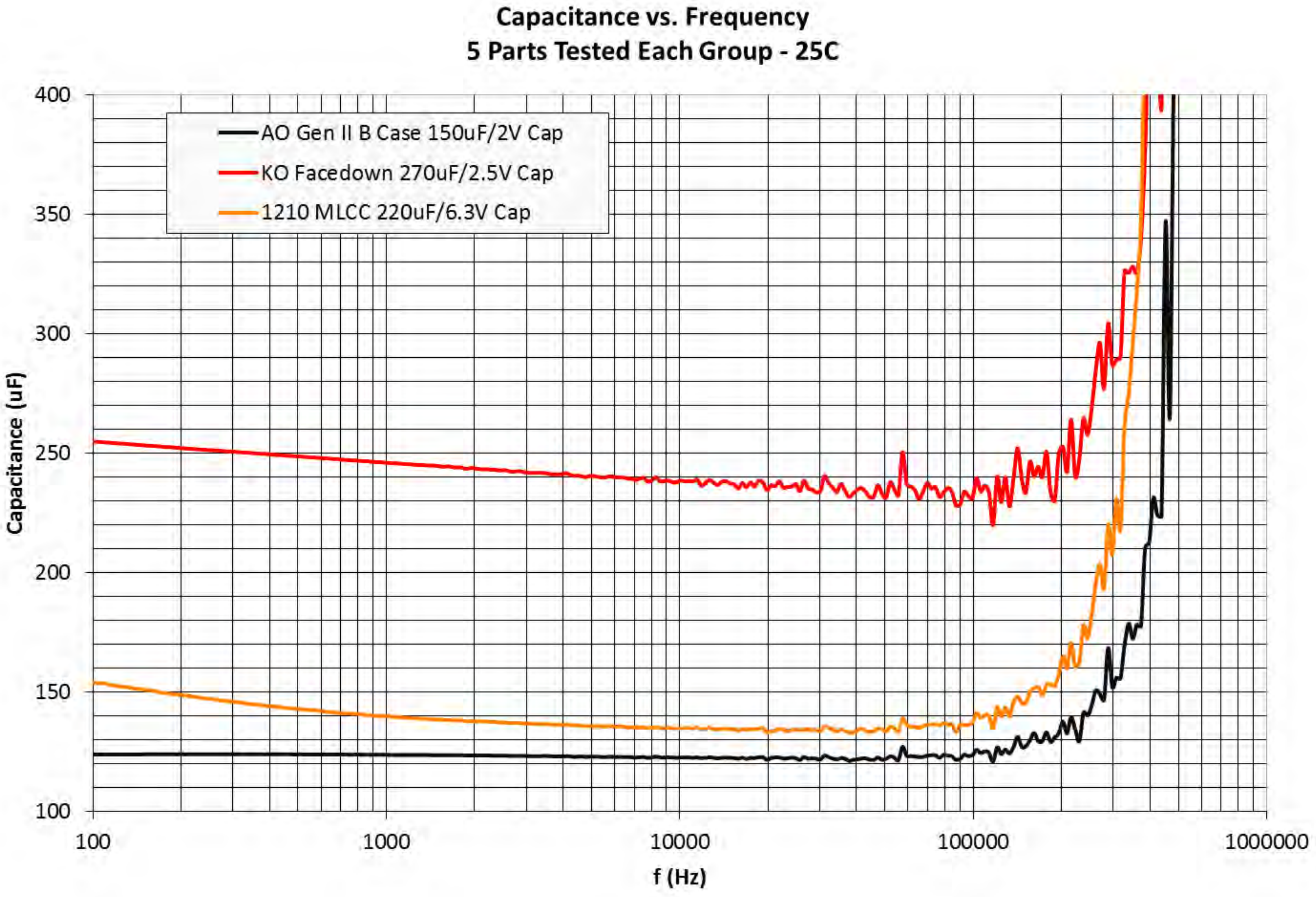
3528 Footprint Impedance Frequency Data

AO Gen II B Case/KO Facedown B Case/1210 MLCC



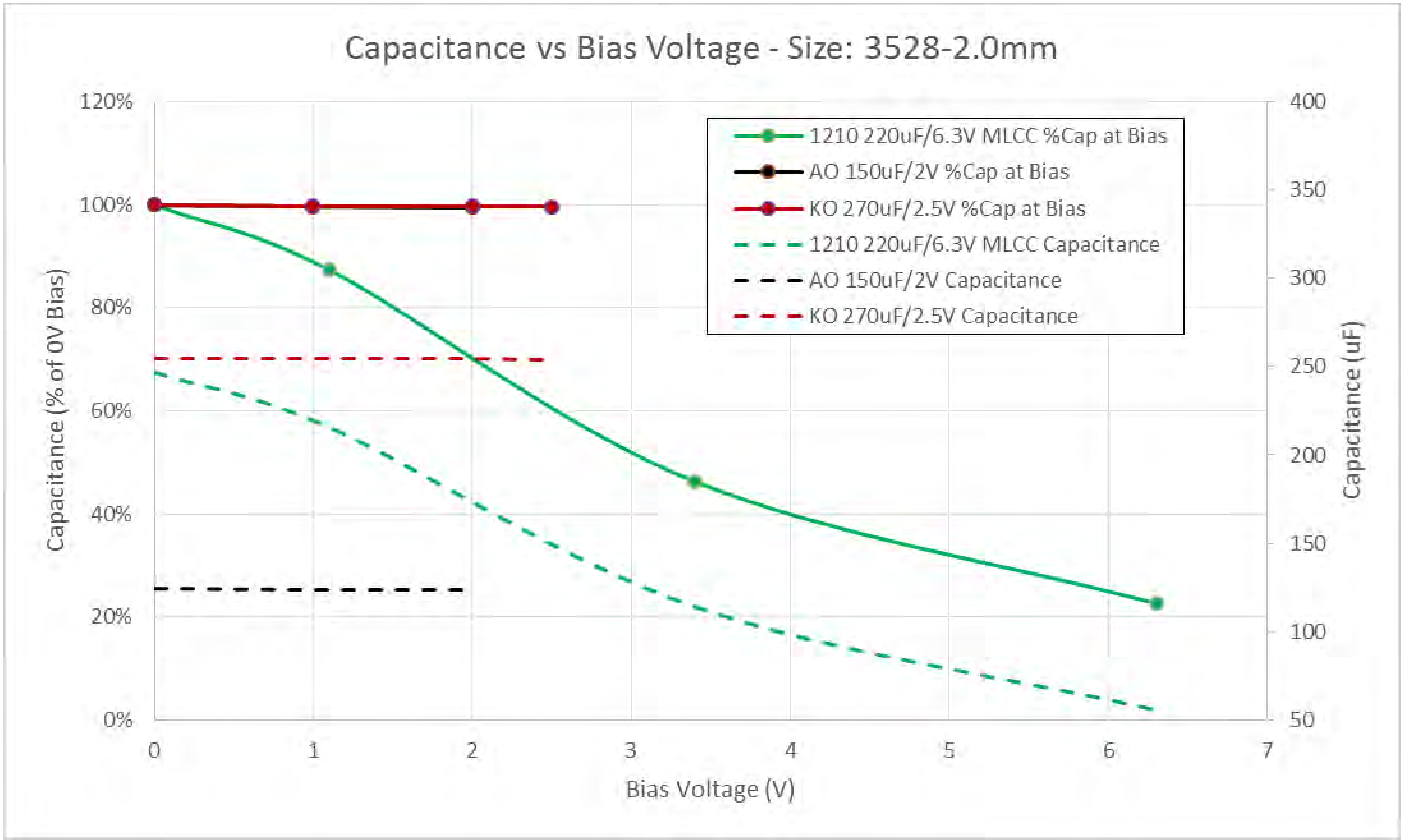
3528 Footprint Capacitance Frequency Data

AO Gen II B Case/KO Facedown B Case/1210 MLCC



Bias Voltage Capacitance

- **One advantage of both polymer systems includes the stability of capacitance over varied bias from zero to rated voltage**

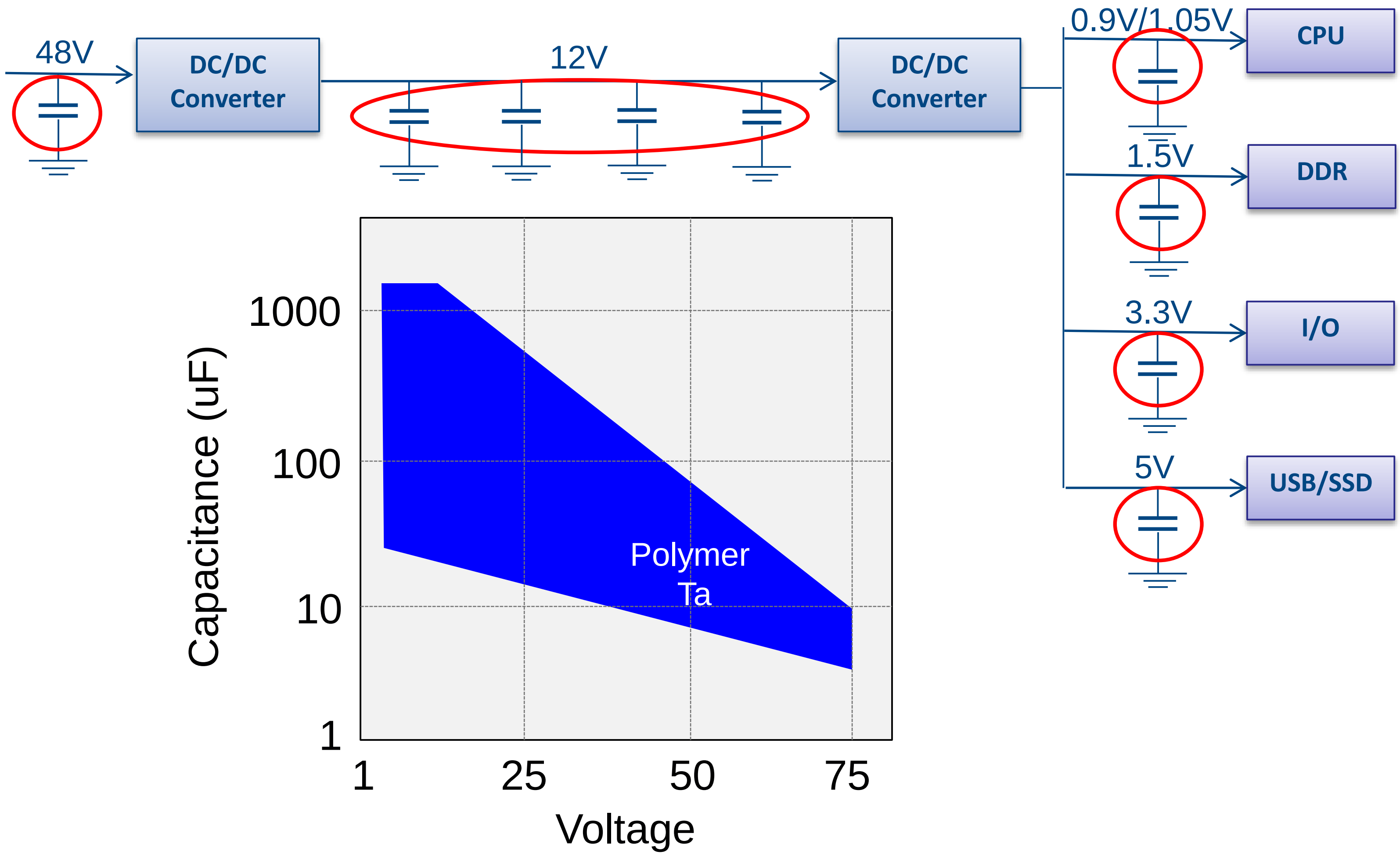


Applications Most Suitable For Polymer Capacitors

DC/DC Converter

Filtering, Decoupling, and Hold Up

Most polymer caps are used in DC/DC power converter applications

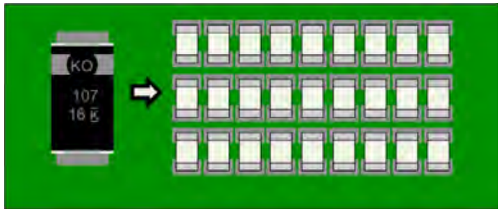


Strengths And Weaknesses

By Dielectric

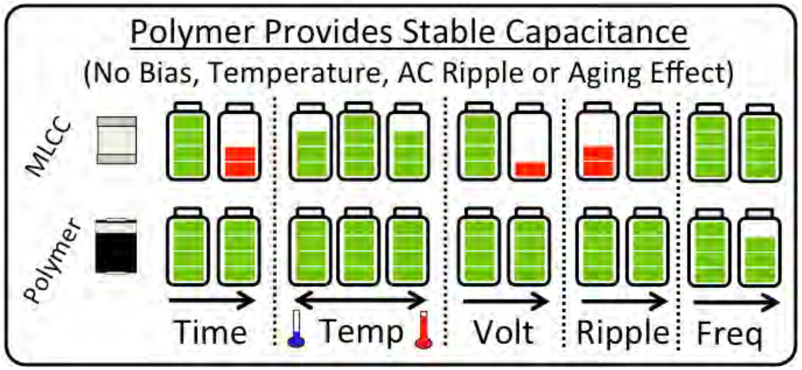
Polymer vs. High Cap MLCC

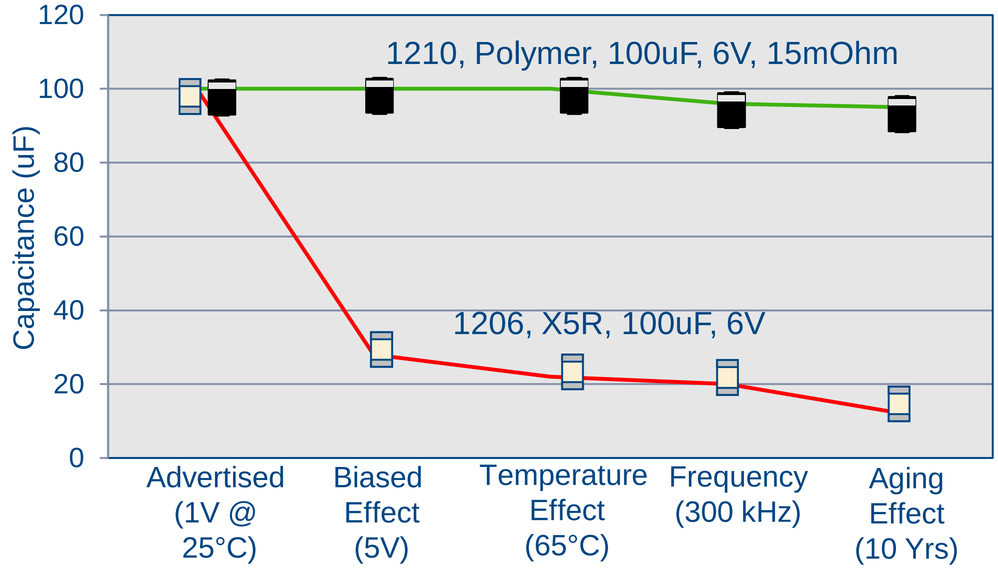
Delivered Capacitance



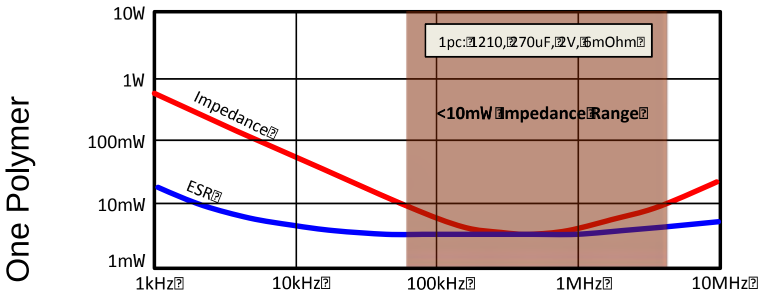
No Piezo Noise

Stable Capacitance

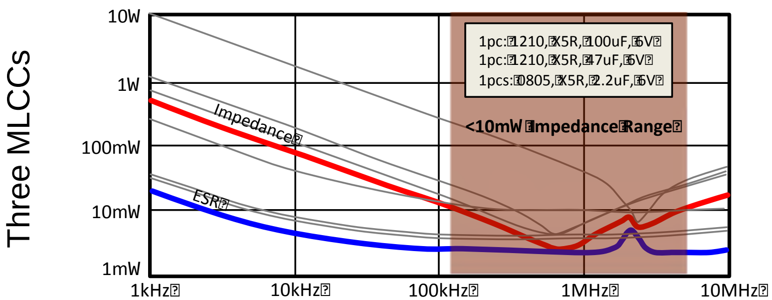




Wider Low Impedance Range

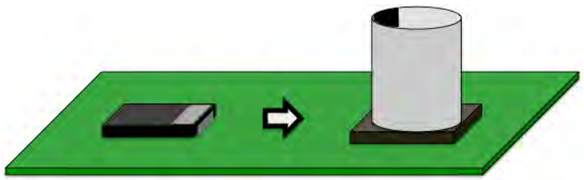


MLCCs have a narrow "sweet spot" for low impedance while polymer has a wide frequency range for BB apps.

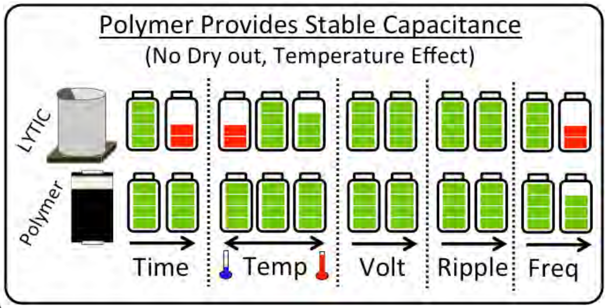


Polymer vs. Aluminum Electrolytic

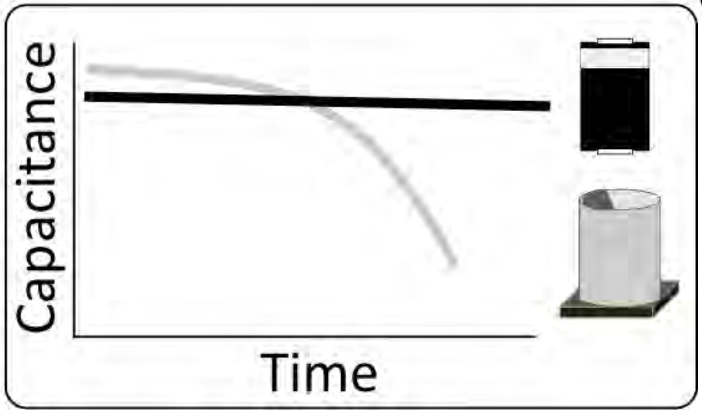
Low Profile



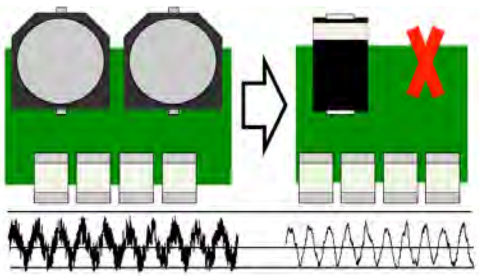
Stable Capacitance



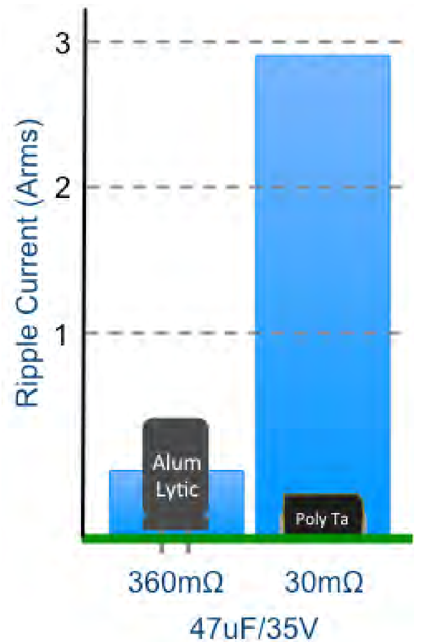
Long Life



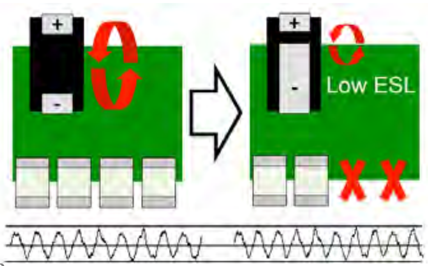
Low ESR



High Ripple Handling

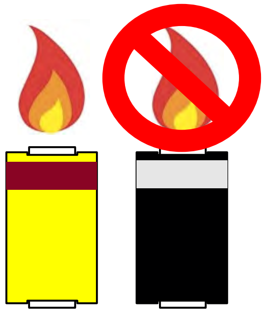


Low ESL

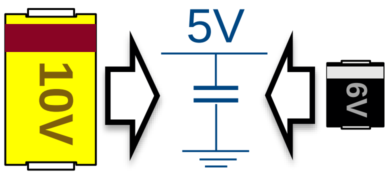


Polymer vs. Traditional Tantalum

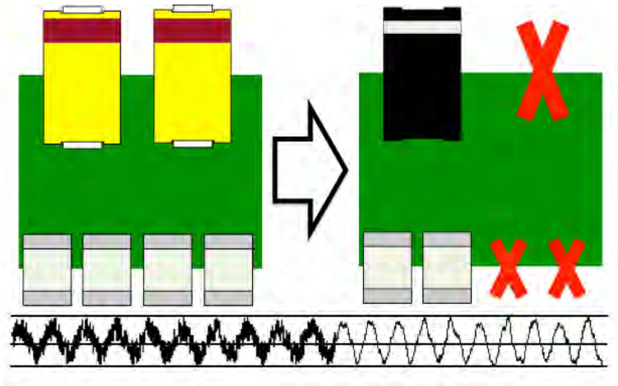
Non-Ignition Failure Mode



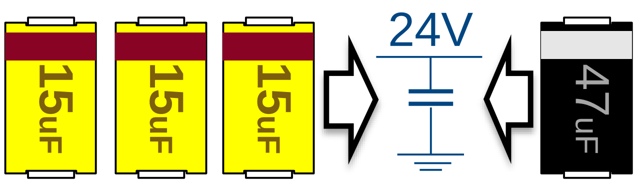
Voltage Derating



Low ESR



Higher Capacitance



When Polymer Is Not The Ideal Choice

- Frequencies Approaching 1MHz
  - Cap vs Frequency results in too great of cap loss compared to MLCC.
- Very Low Leakage Applications
  - Polymer is higher in leakage than MnO_2 type technologies for applications seeking maximum battery life like hearing aids.
- High Temperatures
  - Applications exceeding 125°C are not ideal for polymer caps unless the expected life time use is short (days to weeks).
- Low Capacitance
  - Capacitance needs of picofarads or a few microfarads are too low to be offered in a polymer capacitor.

Polymer Series Lineup

Standard Series

- T520 Polymer 2V-16V
- T521 High Voltage 16V-75V

Application Specific Series

Hi-Temp
- T525 125°C
- T530 125°C High Cap

Hi-Rel COTS
- T540 125°C
- T541 High Cap
- T543 105°C

High Energy
- T545 High Energy

Low ESL
- T528 Low ESL

Miniature Size
- T527 3216-10 Size
- T529 3216-10 & 2012-10 Size

Harsh Environment
- T591 High Humidity
- T598 AEC Q-200

KOCAP
Polymer Capacitors

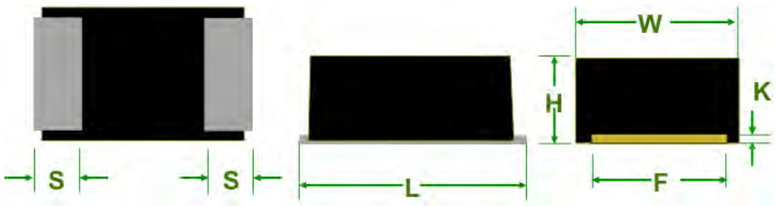
Development Roadmap Summary

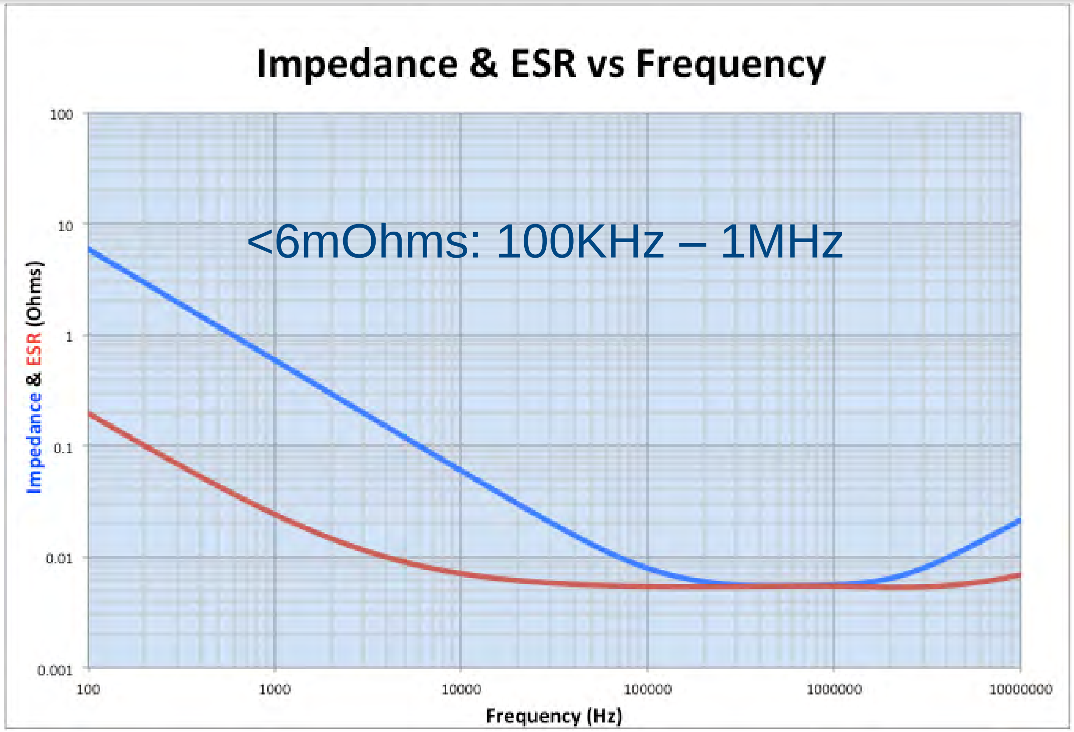
		2015	2016	2017
Low ESR (T520)	3.5x2.8x2.0	9mΩ 2.5V330uF	6mΩ 2.5V330uF	4.5mΩ 2.5V330uF
	3.5x2.8x1.2	18mΩ 6.3V150uF	15mΩ 6.3V220uF	
Low ESL/ESR (T528)	3.5x2.8x2.0	**6mΩ** 2.5V270uF	6mΩ 2.5V330uF	4.5mΩ 2.5V470uF
	3.5x2.8x1.2		9mΩ 2.5V220uF	
High Cap (T520)	3.5x2.8x2.0	6.3V330uF	25mΩ 6.3V330uF	
	3.5x2.8x1.2		15mΩ 6.3V220uF	
Low Profile (T520/T521)	7.3x4.3x1.5	6.3V680uF	16V330uF	
	3.5x2.8x1.2	16V33uF, 25V10uF, 35V6.8uF	25V15uF	35V15uF
	3.5x2.8x1.0		6.3V150uF	16V33uF
12V-48V Higher (T521)	7.3x4.3x4.3	**75V**6.8uF	35V100uF	
	7.3x4.3x2.0		35V47uF, 16V150uF	
High Temp/ High Humidity (T591/T598)	3.5x2.8x1.2 7.3x4.3x2.0 7.3x4.3x3.0	500 Hrs 85/85 & 125C (2-50V)	2.5V470uF 6mΩ (7.3x4.3x2.0)	25mΩ 6.3V330uF (7.3x4.3x2.0)
	3.5x2.8x1.2 7.3x4.3x2.0 7.3x4.3x3.0	1K Hrs 85/85 & 125C (Full AEC Q-200) 2-16V	1K Hrs 85/85 & 125C (Full AEC Q-200) 20-50V	

Low ESL B Cases

Features:

- Small Footprint
- Low Profile
- High Capacitance
- Low ESR





Case Size (LxWxH)	Cap (uF)	Voltage	ESR (mOhms)
3528-20	270	2.5	6
3528-20	270	2.5	9
3528-12	220	2.5	9

Automotive Grade

Full AEC-Q200 Qualified

KOCAP Polymer Capacitors AUTOMOTIVE GRADE

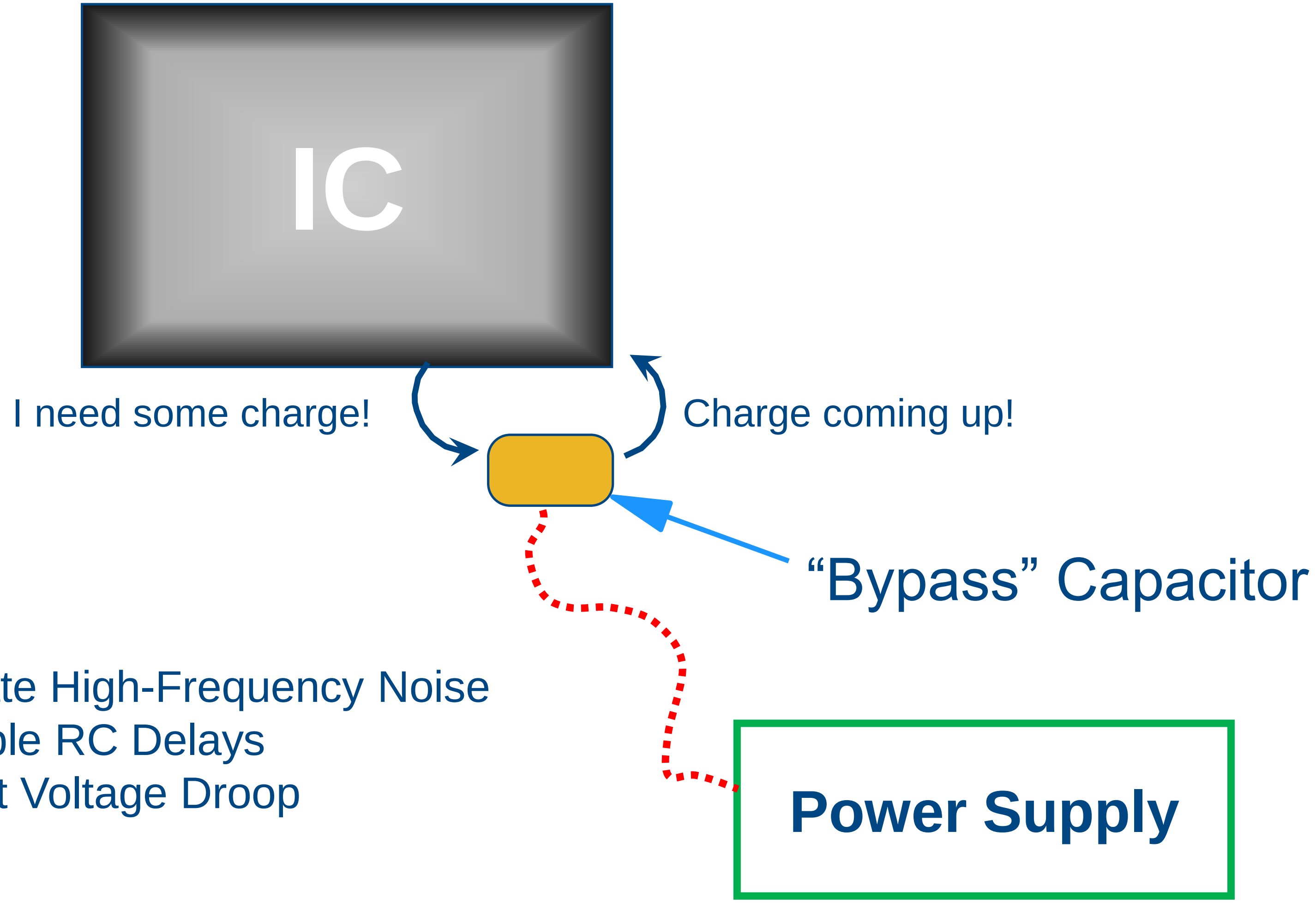
AEC Q-200 Rev D Table of Methods for Tantalum Capacitors				
Stress Test Name	**Conditions**	**Std Poly Series**	**T591**	**T598**
High Temp Exposure (Storage)	125° C, Unbiased, 1000 Hrs	✗	√*	√
Temperature Cycling	-55° C to 125° C, 1000 Cycles	✗	√	√
Biased Humidity	85° C, 85% RH, Biased, 1000 Hrs	✗	(500Hr)	√
Operational Life	125° C, Biased, 1000 Hrs	✗	√	√
Resistance to Solvents	Mil-Std-202, Meth. 215	√	√	√
Mechanical Shock	Mil-Std-202, Meth. 213, Cond F	√	√	√
Vibration	Mil-Std-202, Meth. 208, 5G's-20min	√	√	√
Resistance to Soldering Heat	Mil-Std-202, Meth. 210, Cond D	√	√	√
ESD	AEC-Q200- 002 or ISO/DIS 10605	√	√	√
Solderability	J-STD-002	√	√	√
Terminal Strength	AEC Q200-006	√	√	√

*105°C & 125°C Offerings. See Part Number Table.

Decoupling

Decoupling Principles

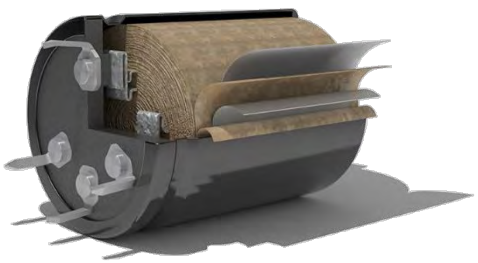
Introduction

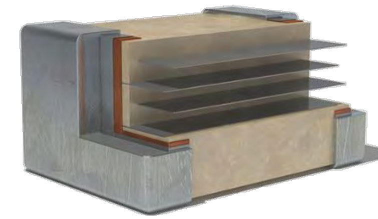


- Eliminate High-Frequency Noise
- Decouple RC Delays
- Prevent Voltage Droop

Decoupling Principles

Different Caps for Different Needs





“High” ESR Electrolytics

Low ESR Electrolytics

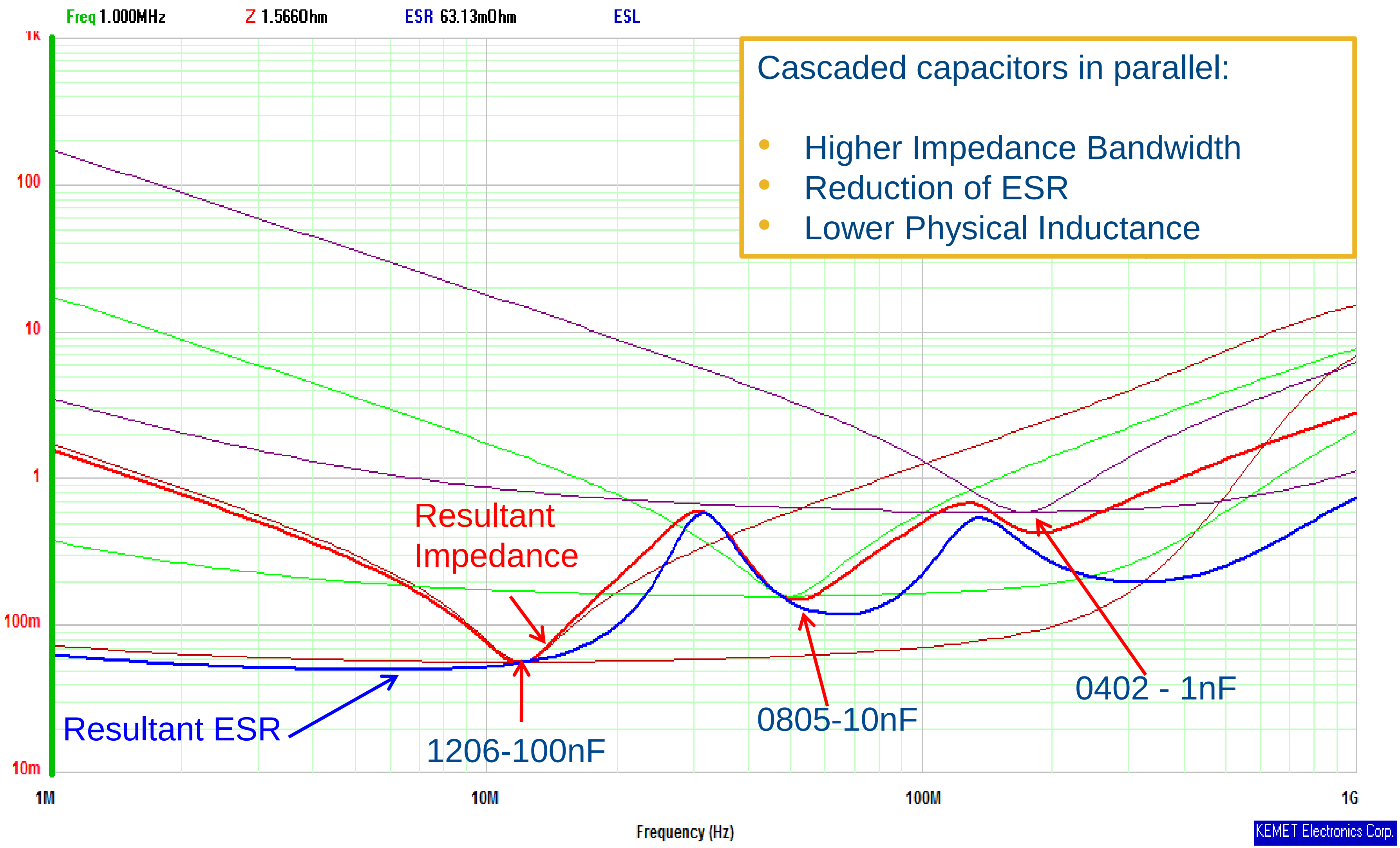
Low ESL Ceramics

- Filters low frequency noise
- Act as charge reservoirs to transient currents

- Low inductance (ESL) and low ESR parts provide high frequency filtering

Decoupling Principles

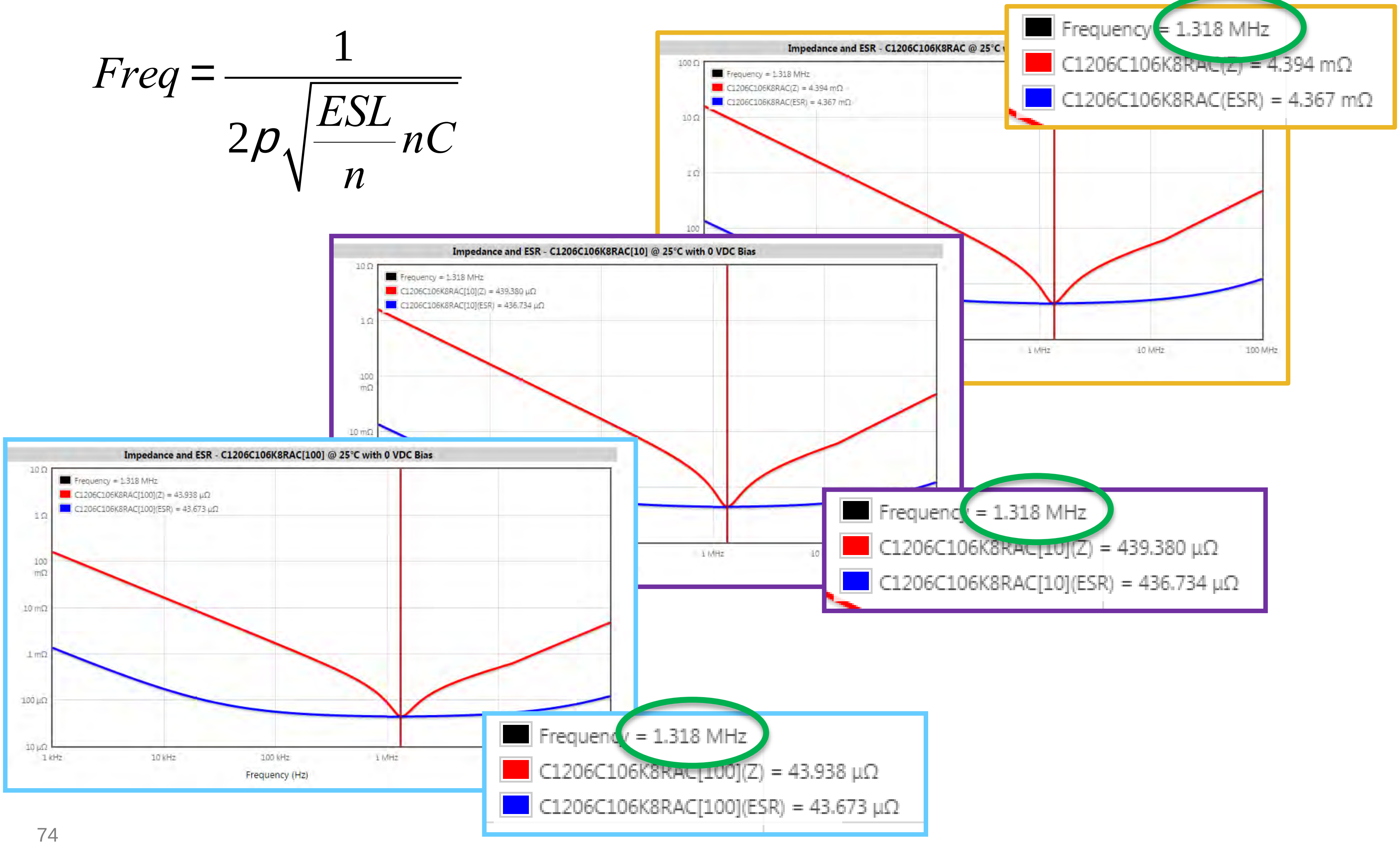
Combining Impedance



Decoupling Principles

Same Value Caps in Parallel

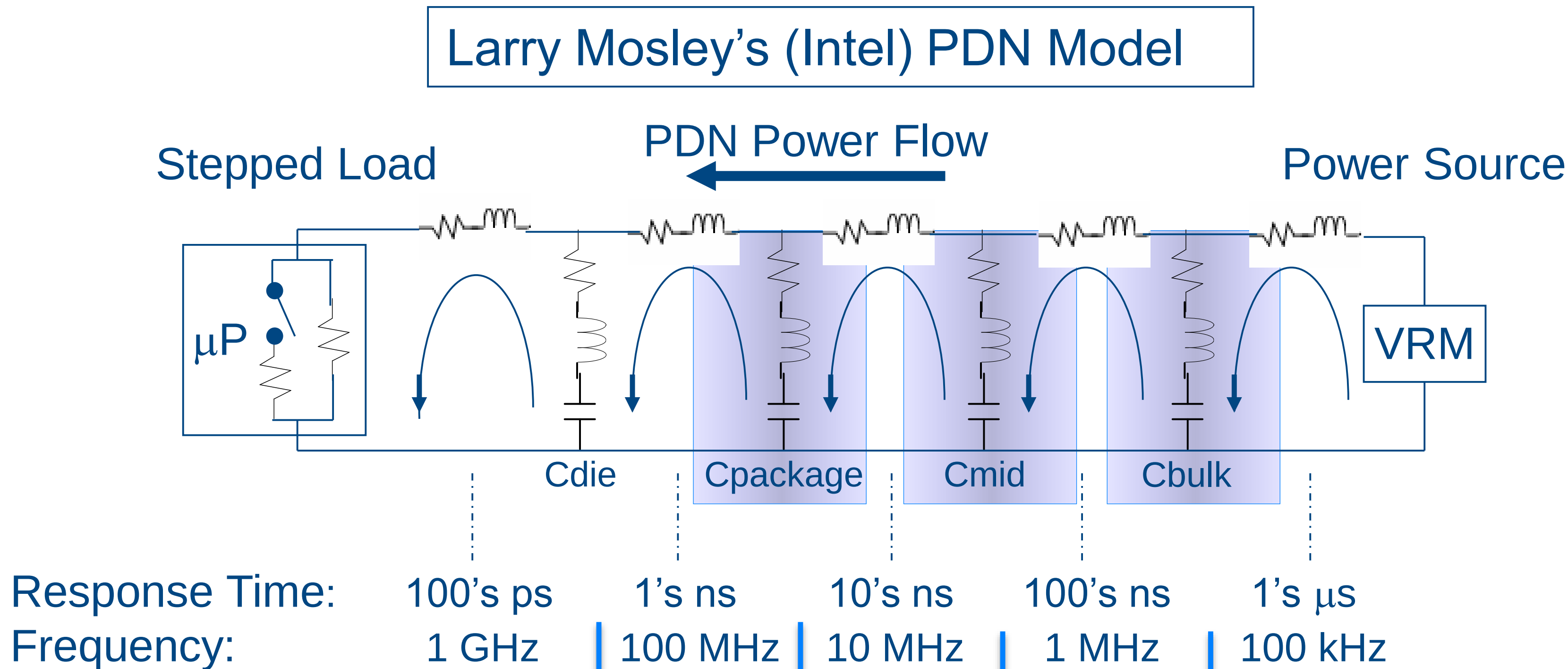
$$Freq = \frac{1}{2p\sqrt{\frac{ESL}{n}nC}}$$



Power Distribution Networks

Power Distribution Network (PDN)

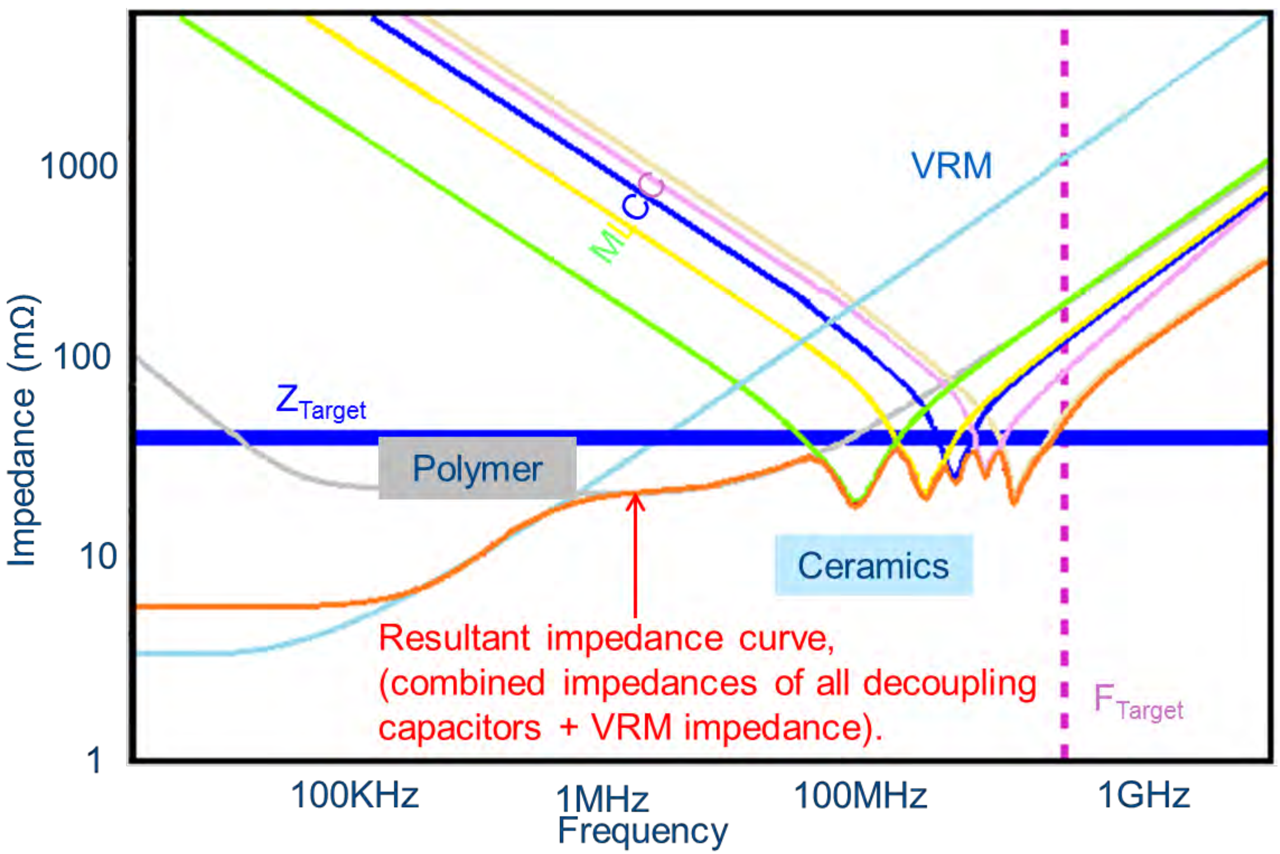
Select Decoupling CAPS to Meet Z_{TARGET}



Larry E. Mosley, "Capacitor Impedance Needs for Future Microprocessors," CARTS 2006 Proceedings. pp. 193-203, ECA (Electronics Components, Assemblies & Materials Association), Arlington, VA, Apr. 2006

Power Distribution Network (PDN)

Impedance = PDN + Capacitor Network



$$Z_{Target} = \frac{V_{Rail}\left(\frac{\%Ripple}{100}\right)}{I_{Max\_Transient}}$$

Filtering

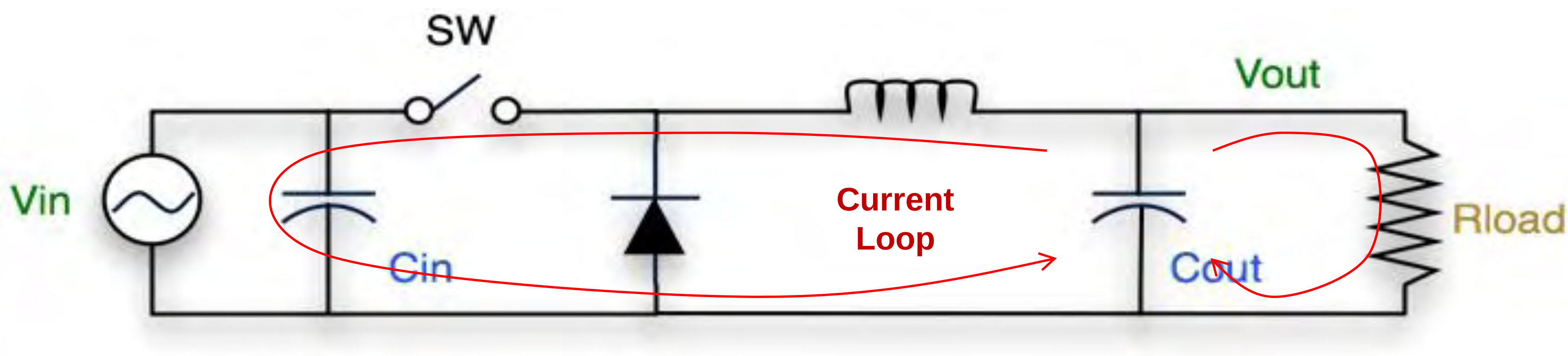
Filtering Principles

Blocking of unwanted signals

Passing of wanted signals

Filtering Principles

Example: DC to DC Converter

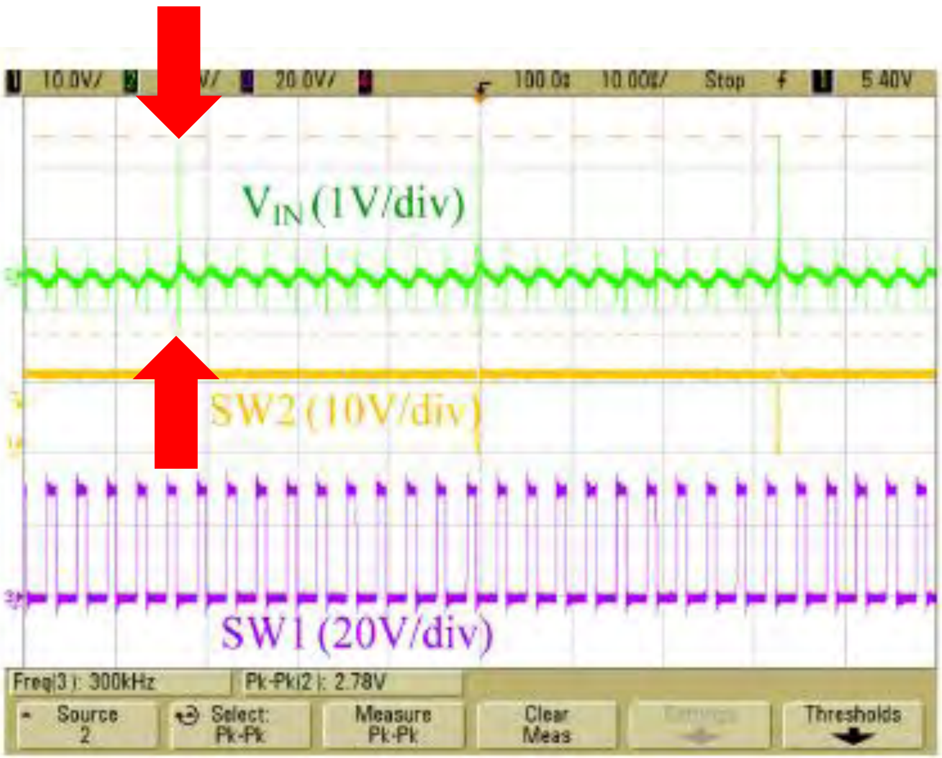


	Frequency	V_{In} > 40V	V_{In} < 40
Ceramic	Mid to High	Good	Good, Low-Cost
Film	Mid to High	Good	Not Ideal
Aluminum Electrolytic	Low	Good, Low-Cost	Not Ideal
Polymer	Mid	Acceptable	Good

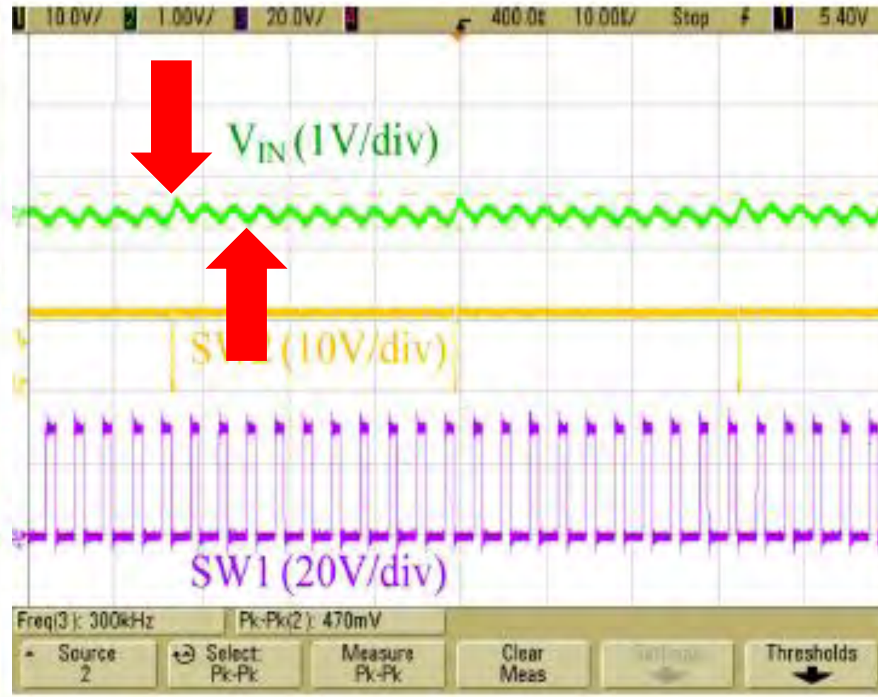
Example Input Filter

$2.78V_{(PP)}$ without filtering

$0.47V_{(PP)}$ with filtering

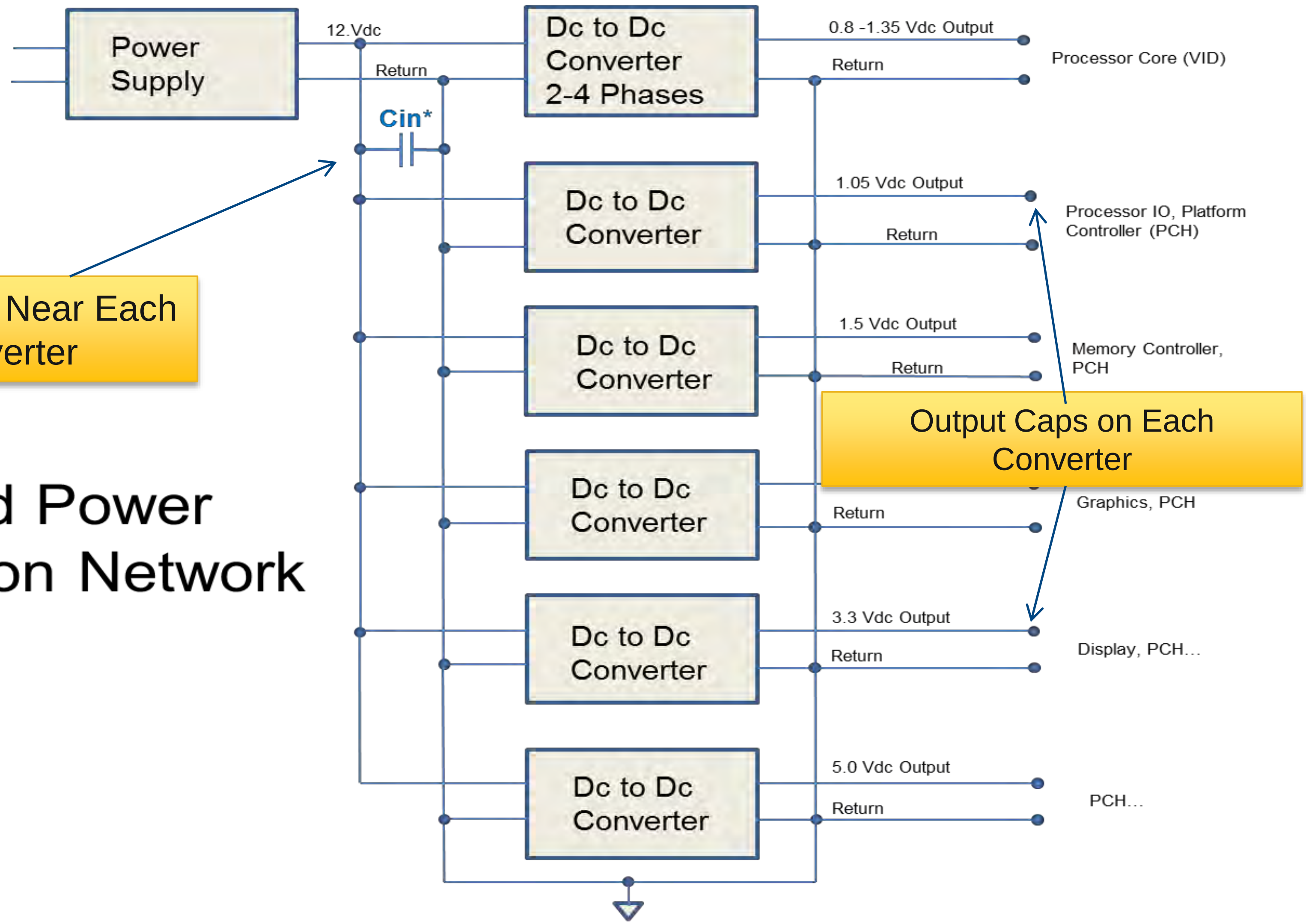


V_{IN} = 10V, V_{OUT} = 30V, I_{OUT} = 3A
W/O Input Filter: Short L2 and L3, Remove C_{IN2}
V_{IN} Peak-to-Peak Ripple = 2.78V



V_{IN} = 10V, V_{OUT} = 30V, I_{OUT} = 3A
W Input Filter: Stuff L2, L3 and C_{IN2}
V_{IN} Peak-to-Peak Ripple = 0.47V

Example Power Distribution System



Input Caps Near Each Converter

Simplified Power Distribution Network

Output Filter Capacitors

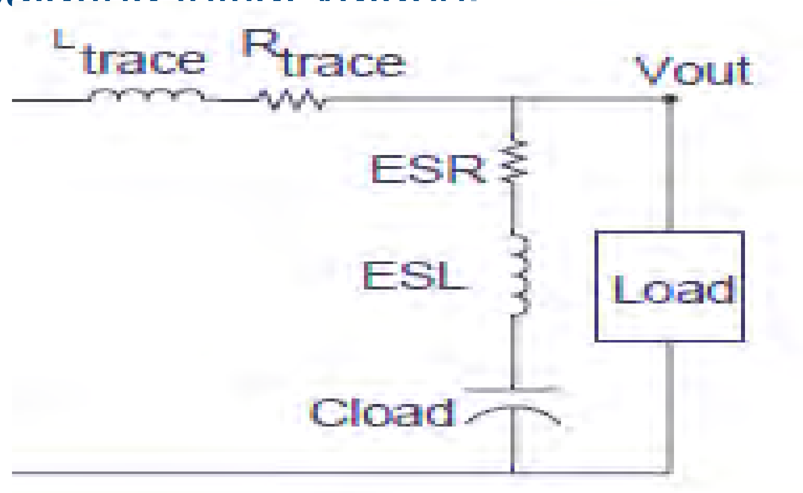
ESR and ESL Considerations

The DC to DC output voltage for a load transient can be defined as:

$$V_{out}(t) = V_{out\_initial} - ESL\left(\frac{di_{laod}}{dt}\right) - ESR * i_{load}(t)$$

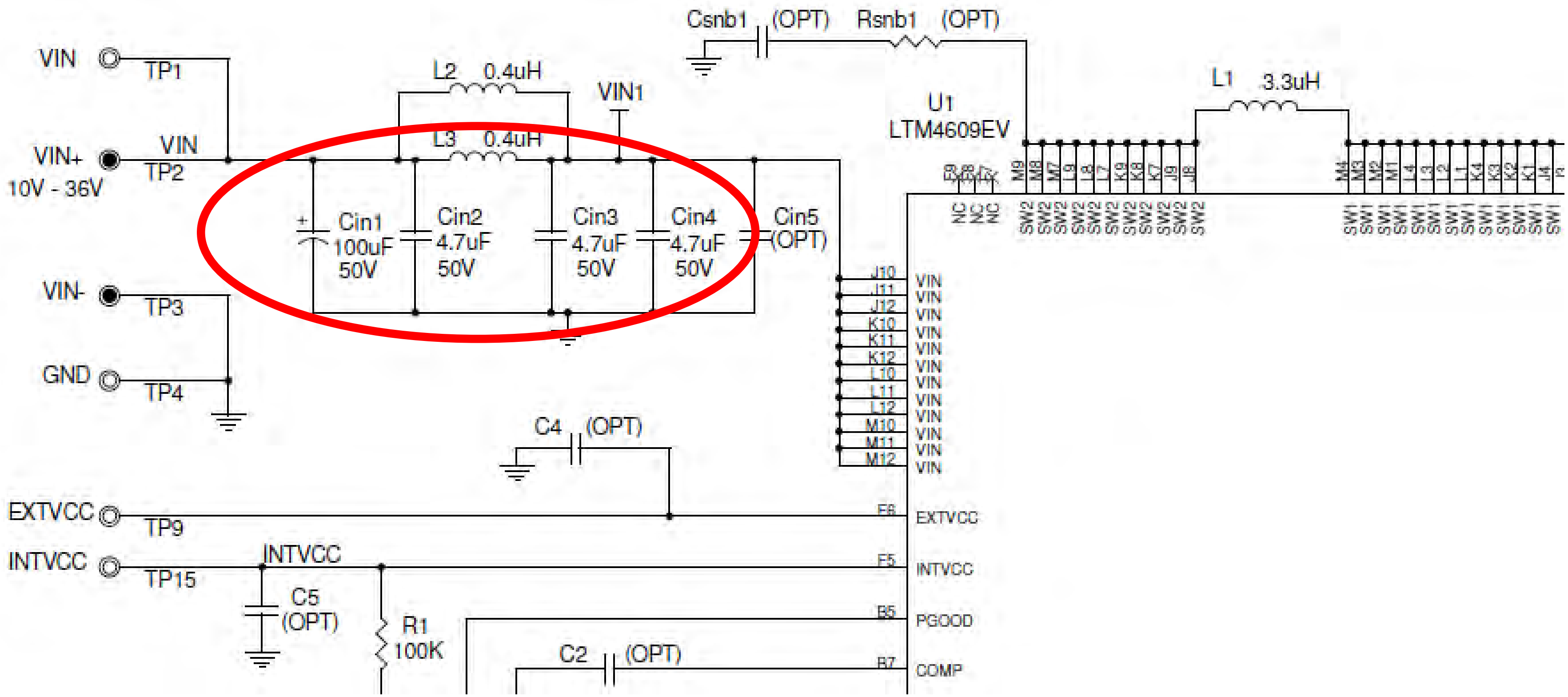
The magnitude of the voltage drop is proportion to ESR * load current and can be compensated for when calculating initial values.

$$C = I * \frac{dt}{(dv - (ESR * i_{load}))}$$



Example Input Filter

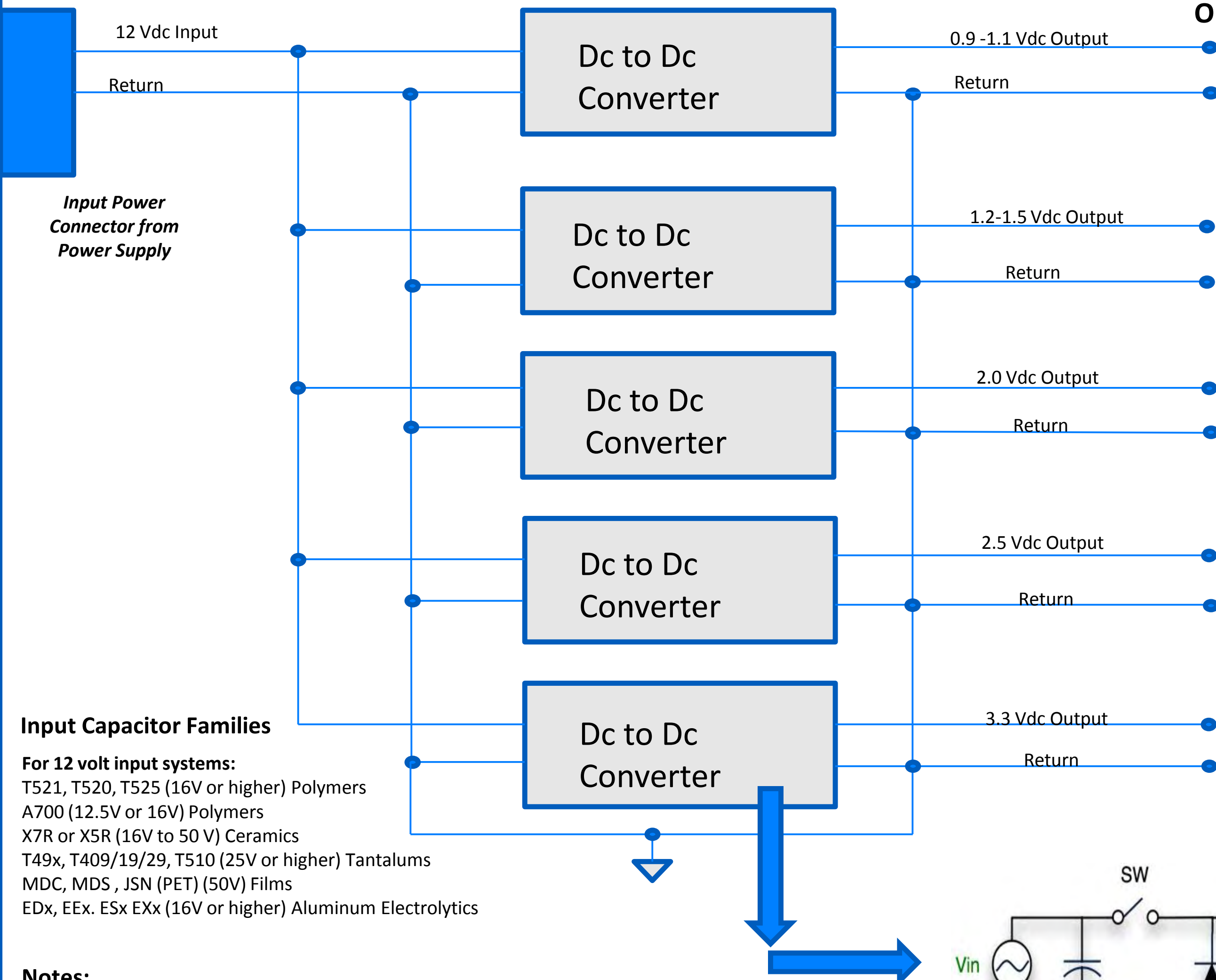
- Cin1 is 100uF, 50V aluminum electrolytic (polar)
- Cin2, Cin3, Cin4 , are X7R, 4.7µF, 50V, 10%, 1210



Linear Technology, DEMO MANUAL DC1477A

Simplified Power Distribution System

Electronic Components KEMET CHARGED.



Output Capacitor Families

0.9 -1.1 Vdc Output:
- T520, T525 (2.5V), Low ESR, Polymers
- T528 (2.5V), Low ESR/ESL, Polymers
- A700 (2V), Low ESR, Polymers
- X7R and X5R (4V and 6.3V) Ceramics
- T49x, T409/19/29, T510 (2.5V or higher) Tantalums
- EDx, EEx. ESx EXx (4V or higher) Aluminum Electrolytics

1.2-1.5 Vdc Output:
- T520, T525 (2.5V), Low ESR, Polymers
- T528 (2.5V), Low ESR/ESL, Polymers
- A700 (2V), Low ESR, Polymers
- X7R and X5R (4V and 6.3V) Ceramics
- T49x, T409/19/29, T510 (4V or higher) Tantalums
- EDx, EEx. ESx EXx (4V or higher) Aluminum Electrolytics

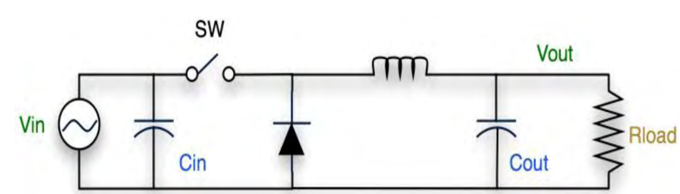
2.0 Vdc Output:
- T520, T525 (2.5V), Low ESR, Polymers
- T528 (2.5V), Low ESR/ESL, Polymers
- A700 (2V), Low ESR, Polymers
- X7R and X5R (4V and 6.3V) Ceramics
- T49x, T409/19/29, T510 (4V or higher) Tantalums
- EDx, EEx. ESx EXx (4V or higher) Aluminum Electrolytics

2.5 Vdc Output:
- T520, T525 (3V or 4V), Low ESR, Polymers
- T528 (3V or 4V), Low ESR/ESL, Polymers
- A700 (2.5V), Low ESR, Polymers
- X7R and X5R (4V and 6.3V) Ceramics
- T49x, T409/19/29, T510 (6.3V or higher) Tantalums
- EDx, EEx. ESx EXx (4V or higher) Aluminum Electrolytics

3.3 Vdc Output:
- T520, T525 (4V), Low ESR, Polymers
- T528 (4V), Low ESR/ESL, Polymers
- A700 (4V), Low ESR, Polymers
- X7R and X5R (6.3V) Ceramics
- T49x, T409/19/29, T510 (10V or higher) Tantalums
- EDx, EEx. ESx EXx (6.3V or higher) Aluminum Electrolytics

Input Capacitor Families

For 12 volt input systems:
T521, T520, T525 (16V or higher) Polymers
A700 (12.5V or 16V) Polymers
X7R or X5R (16V to 50 V) Ceramics
T49x, T409/19/29, T510 (25V or higher) Tantalums
MDC, MDS , JSN (PET) (50V) Films
EDx, EEx. ESx EXx (16V or higher) Aluminum Electrolytics



Simplified Dc to Dc converter

Notes:
- Cell Phone uses X5R Ceramics for input and output capacitors
- Automotive uses X7R (25 and 50V) Ceramics due to Load Dump on 12V input
- Military and Commercial aircraft – use 28 Volt input, T521/540/541 (35 and 50 volts) Polymers and X7R (50-100 volts) Ceramics for inputs
- Telecom uses 100V Films and Ceramics on 48V lines.

Rev. 121009PAB

Decoupling Networks

Advantages of Capacitors in Parallel

- Increased bulk Capacitance
- Lower ESR
- Lower physical inductance
  - Larger caps have larger ESL
  - Smaller caps in parallel do not affect ESL
- Higher impedance bandwidth

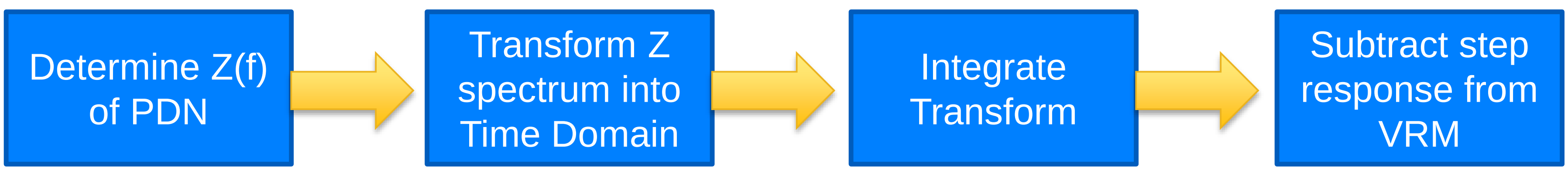
$$Freq = \frac{1}{2p\sqrt{\frac{ESL}{n} nC}}$$

Equal capacitors in *Parallel* do not alter the SRF

Calculating Target Impedance

- Needed for Z_{target}
  - Max transient Current
  - Rail Voltage
  - Max AC Ripple (% of Supply)
  - f_{Target} is max switching frequency

$$Z_{Target} = \frac{V_{Rail}\left(\frac{\%Ripple}{100}\right)}{I_{Max\_Transient}}$$



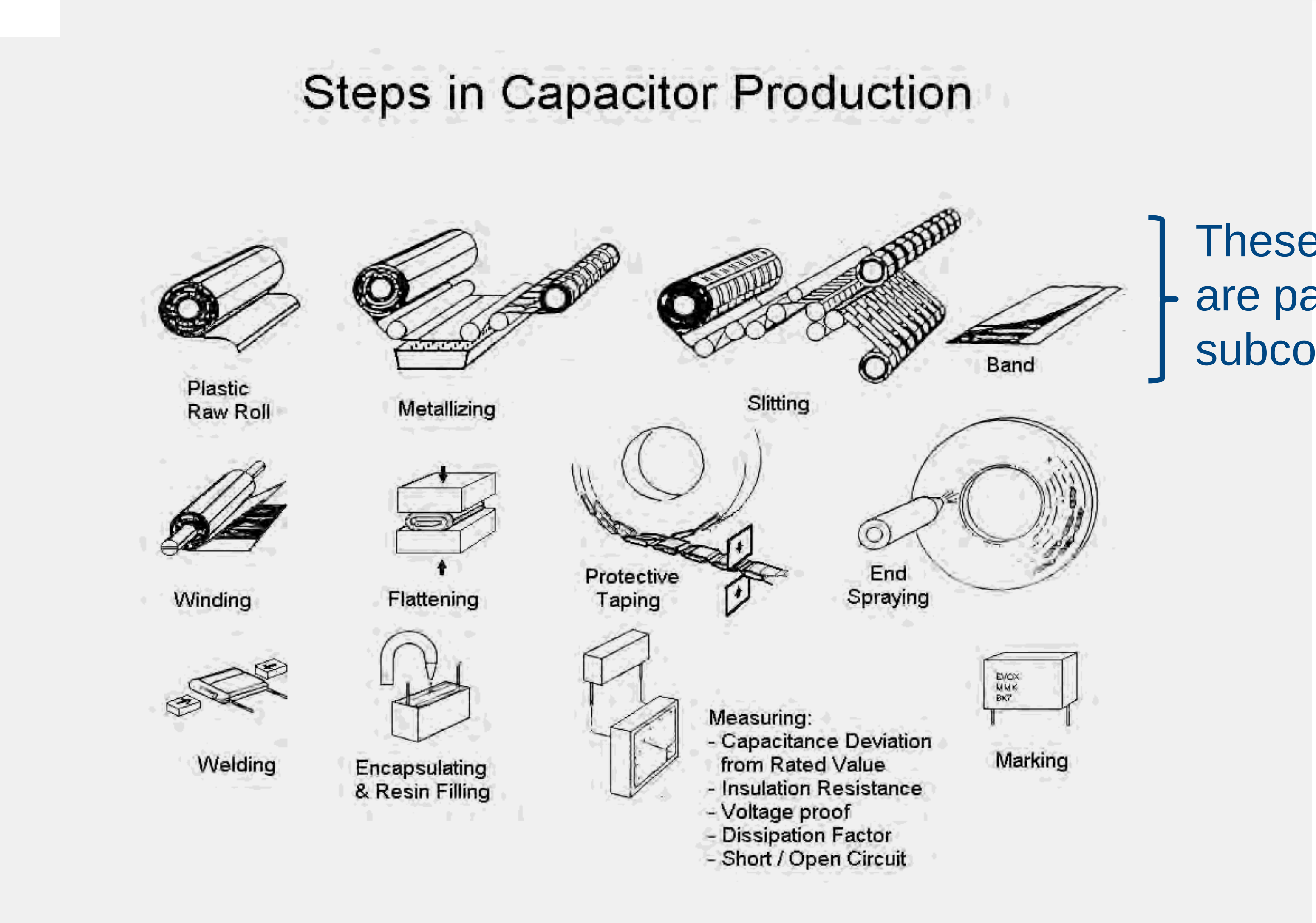
http://www.electrical-integrity.com/

Istvan Novak, "Comparison of Power Distribution Network Design Methods" DesignCon 2006, Santa Clara, CA February 6-9, 2006

Film

The Capacitance Company
KEMET
CHARGED.™

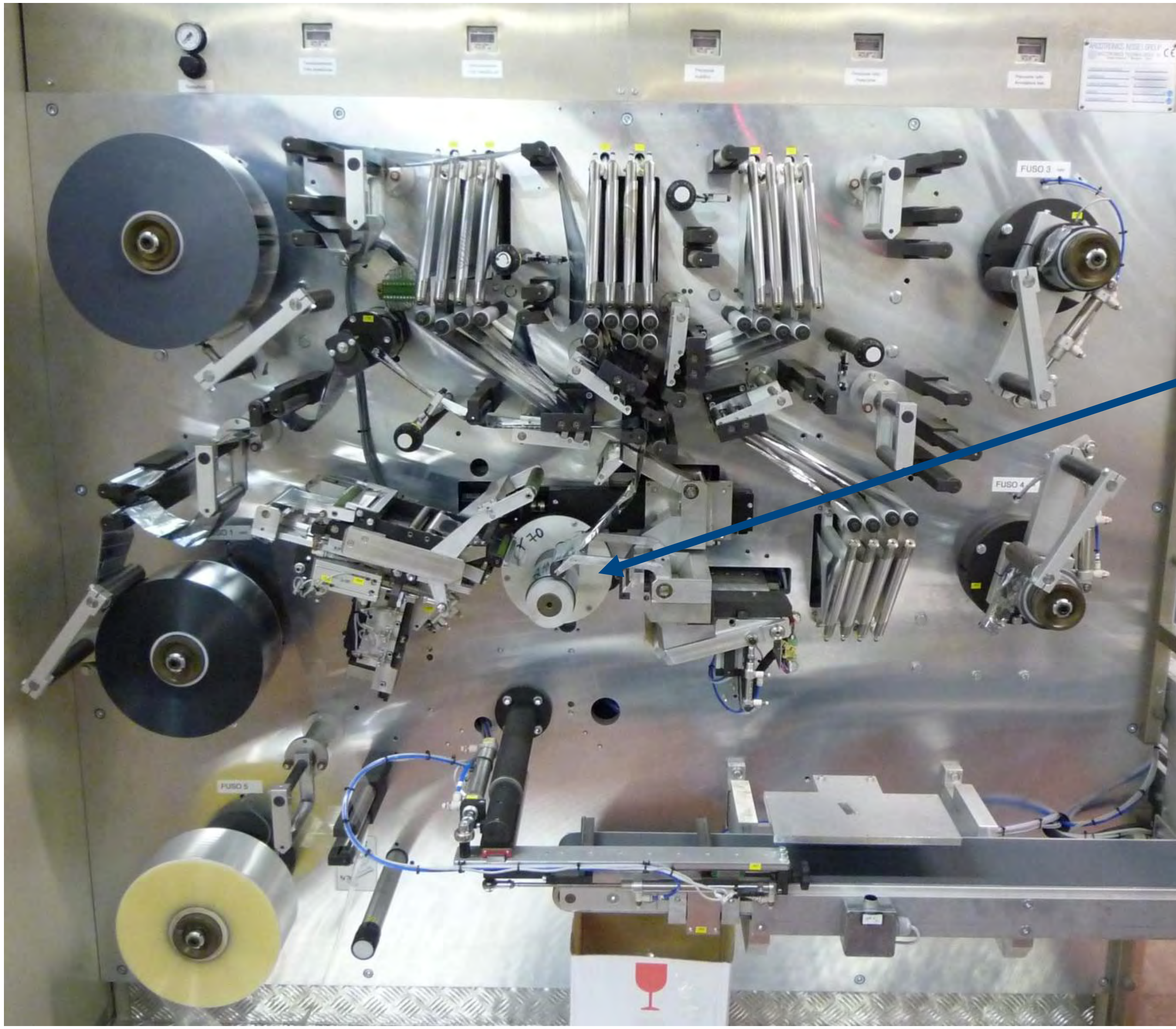
Simplified Wound Capacitor
Production Process

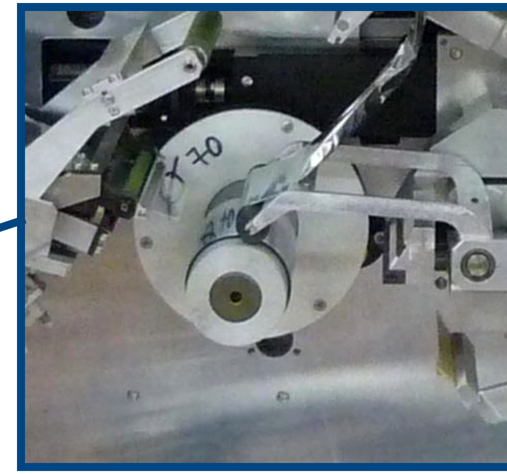


These steps are partly subcontracted

Electronic Components KEMET CHARGED.

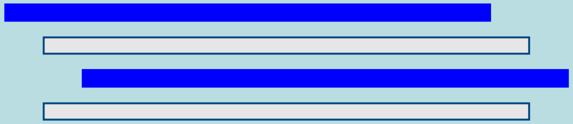
Soft-Winding Technology:
Winding and Pre-Flattening



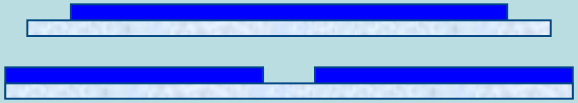


Various Winding Constructions 1

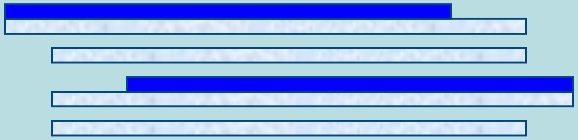
Single Design - Single layer



Film Foil



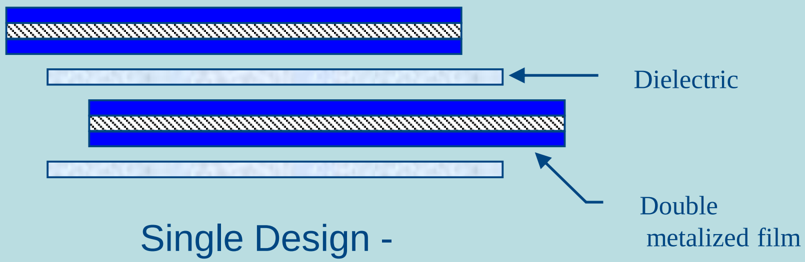
Dual Section (series) Design - Single layer



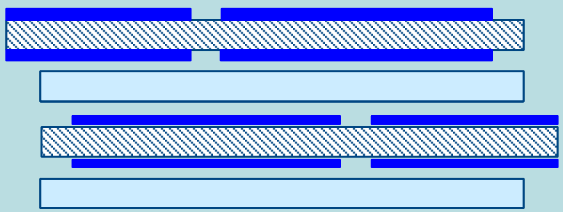
Single Design – Multi-layer dielectric

Various Winding Constructions 2

Electronic Components KEMET CHARGED.

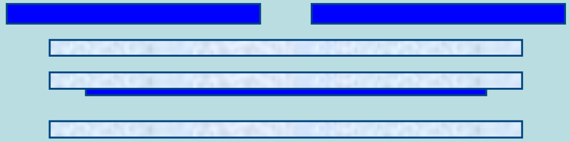


Single Design -
double metalized, single layer dielectric



Triple section (series) Design -
double metalized, single layer dielectric

Dual section (series) Design -
double metalized, single layer dielectric

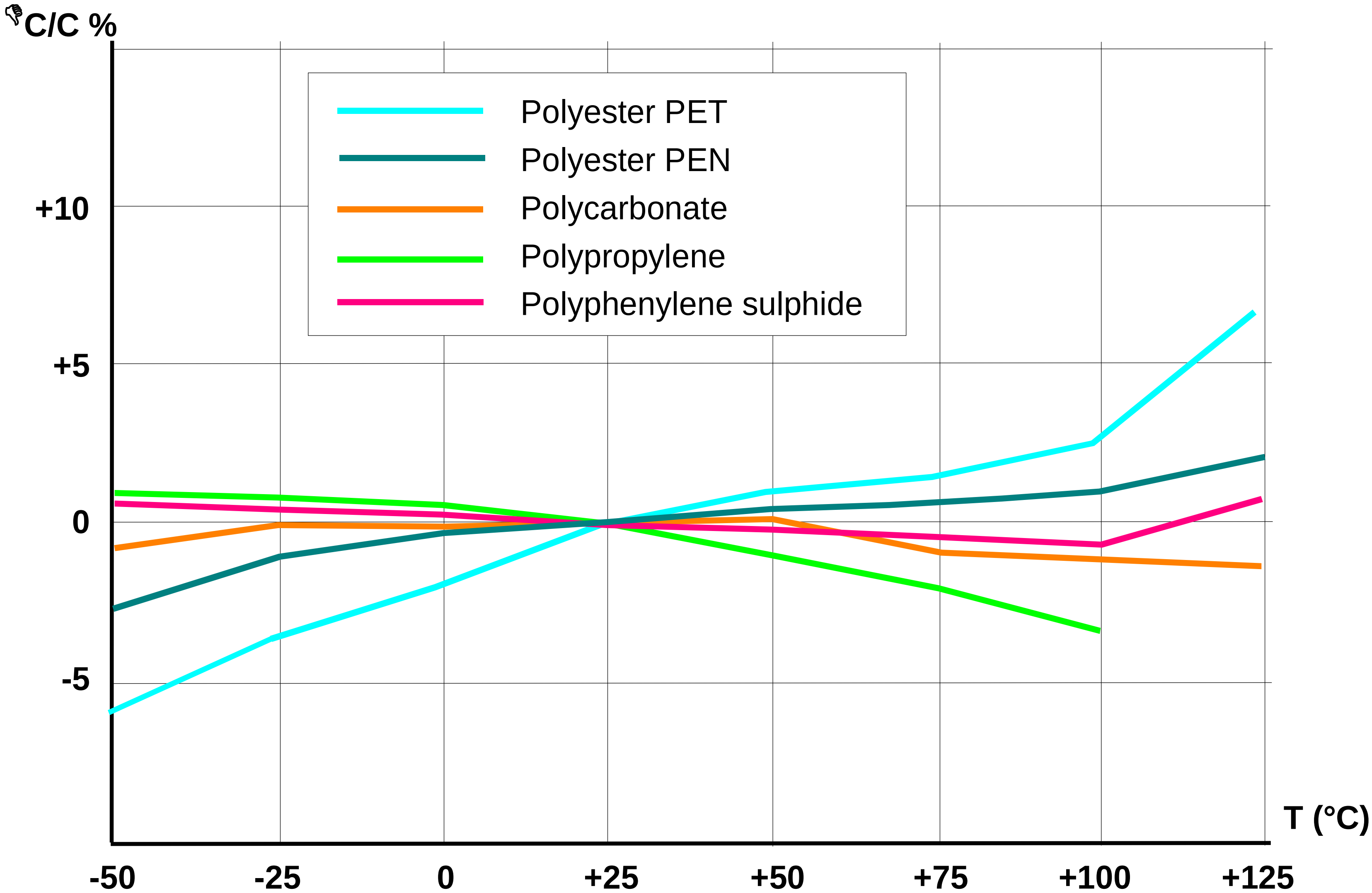


Dual section (series) Design -
Foil /metalized, multi-layer dielectric

Dominant Film Types*

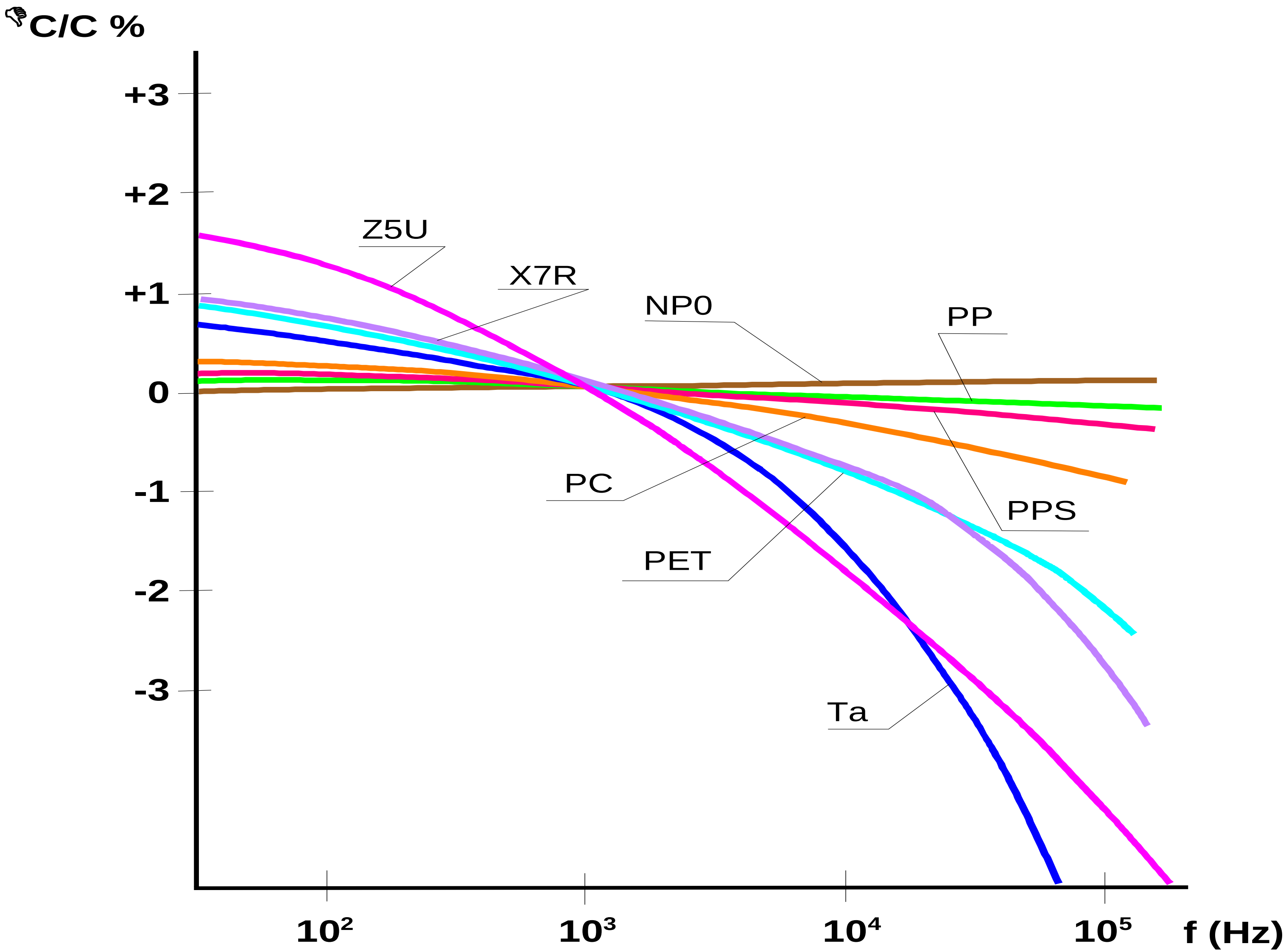
Film	Code	Best Tol. (±%)	ΔC -25°C to 85°C	Aging (%/yr)	DF (Typ)	Max. Temp. (°C)
polypropylene	PP	1	3%	0.2	0.05%	105
polyethylene terephthalate	PET	5	5%	0.4	0.50%	140
polyethylene naphthalene	PEN	5	5%	0.4	0.48%	155
polyphenylene sulfide	PPS	2	0.5%	0.3	0.20%	260

Capacitance vs. Temperature

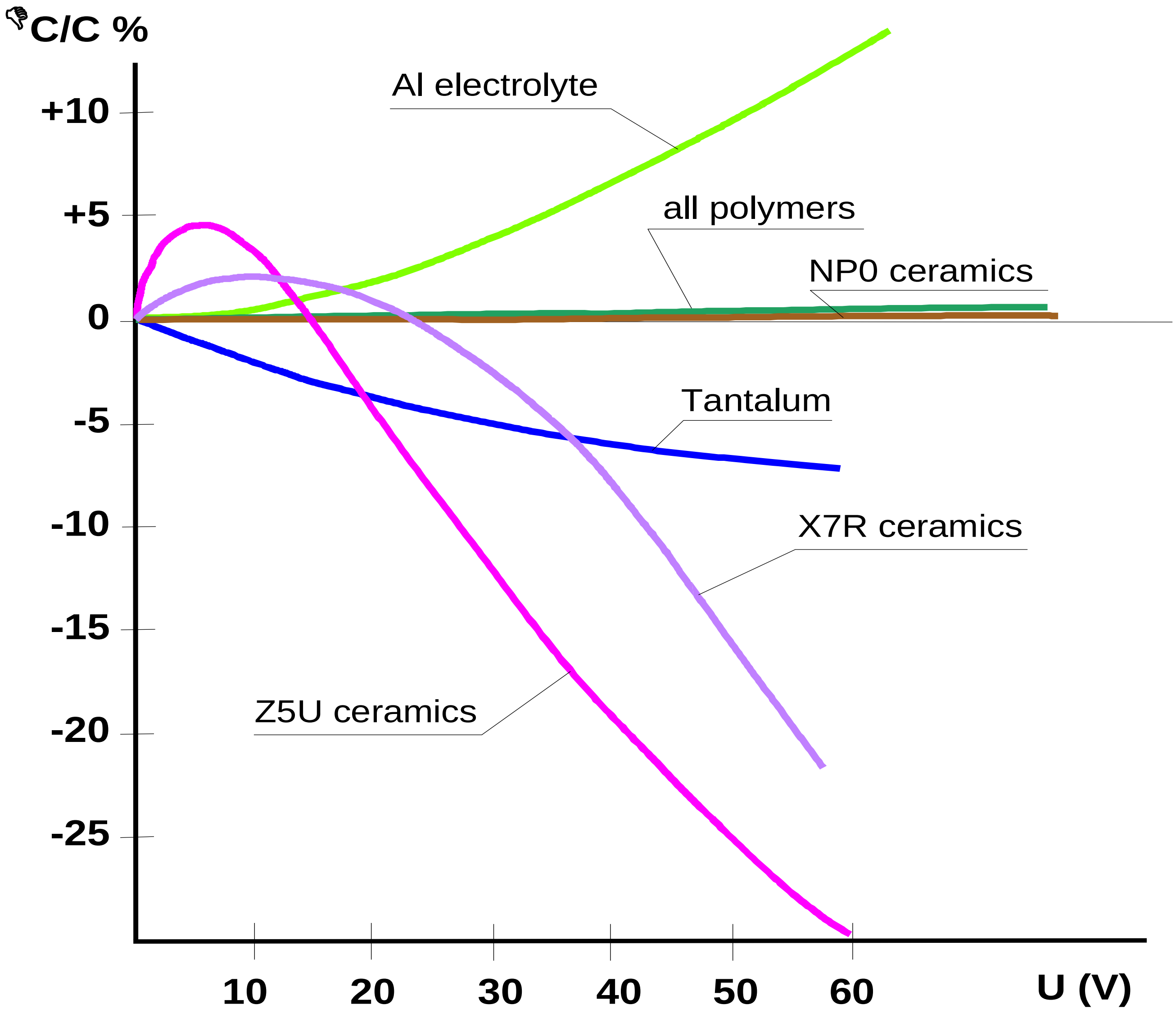


Capacitance vs. Frequency

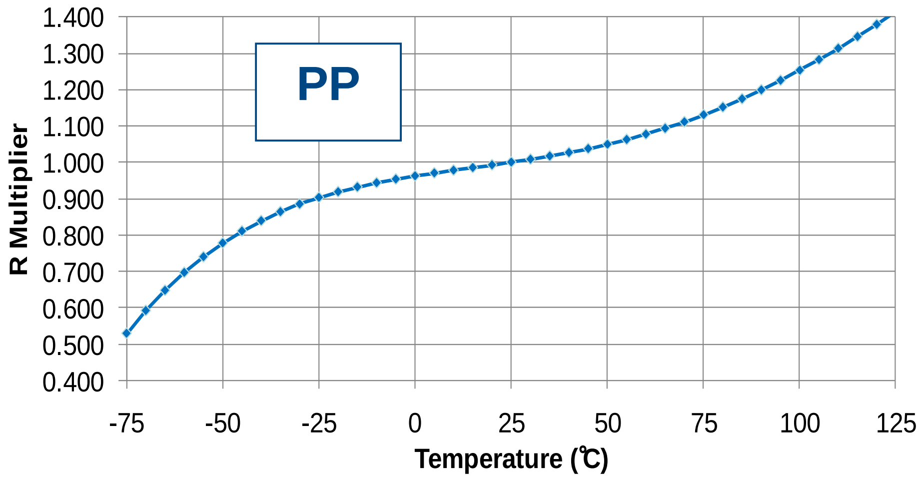
Electronic Components KEMET CHARGED.

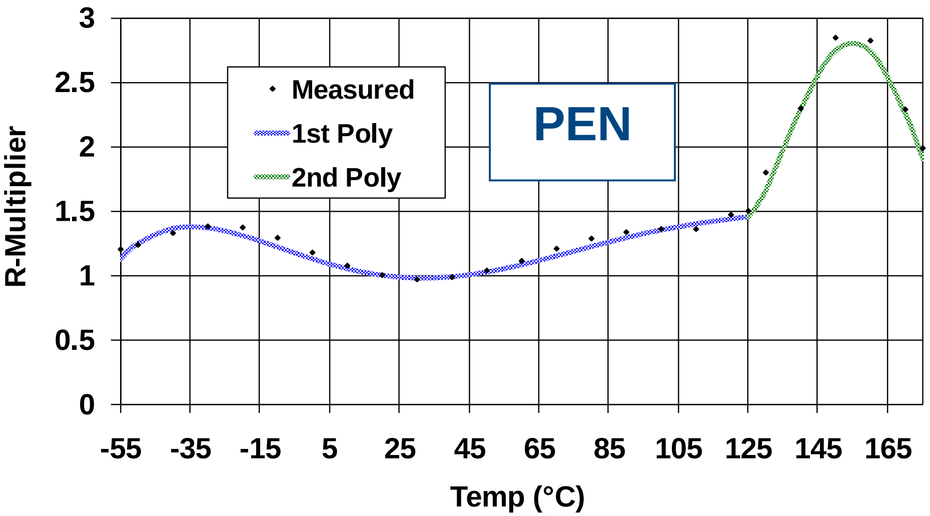


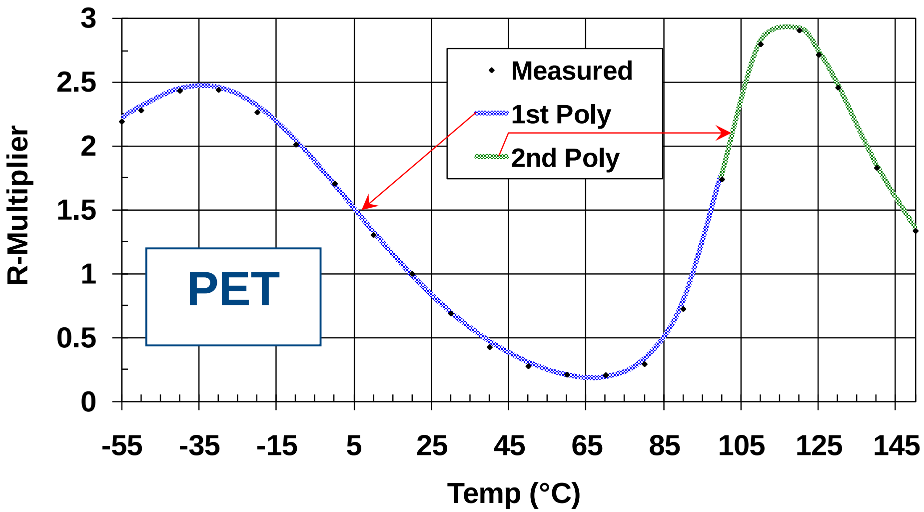
Capacitance vs. DC Voltage

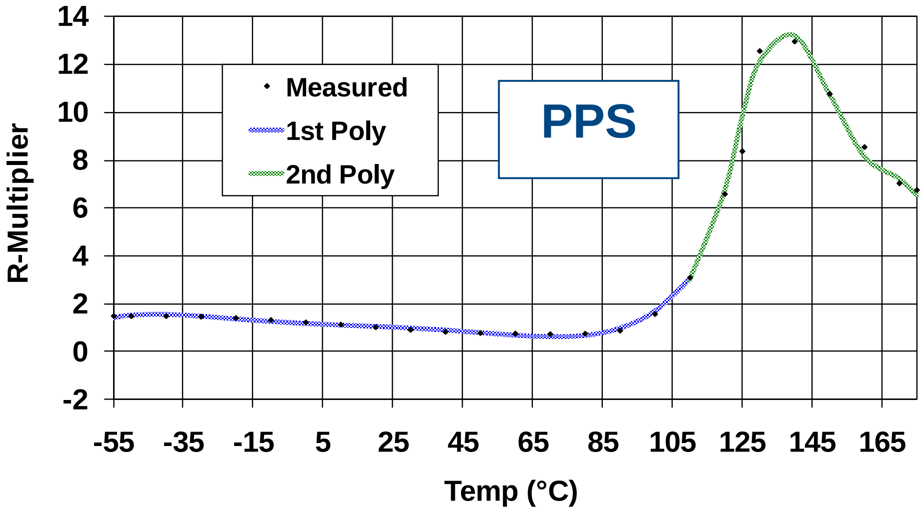


ESR vs. Temperature





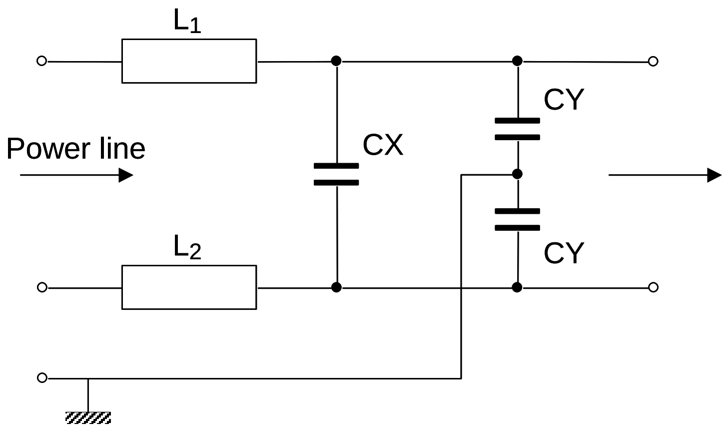




EMI Suppression Requirements
Safety Caps – AC Part of SMPS

Mains network and electronic equipment EMI suppression applications:

- SMPS for home electronics including PCs ,TVs, game consoles etc
- SMPS for office equipment
- Industrial and house hold appliances/ white goods
- Lighting ballasts



General Requirements:

Life expectancy:	>10 years (150k hours)
Rated voltage:	120 to 760 Vac
Transient voltage robust:	High dv/dt (peak)
Self-healing	
Safety standards:	IEC 60384-14
	EN 60384-14 (ENEC)
	UL 60384-14

Capacitor Function:

EMI / RFI suppression

The standards are globally practically identical, also China (CQC) uses the IEC standard

Capacitance Stability Example
Comparison of Different X2 Types

Electronic Components KEMET CHARGED.

Test in outdoor conditions continously in a Nordic country

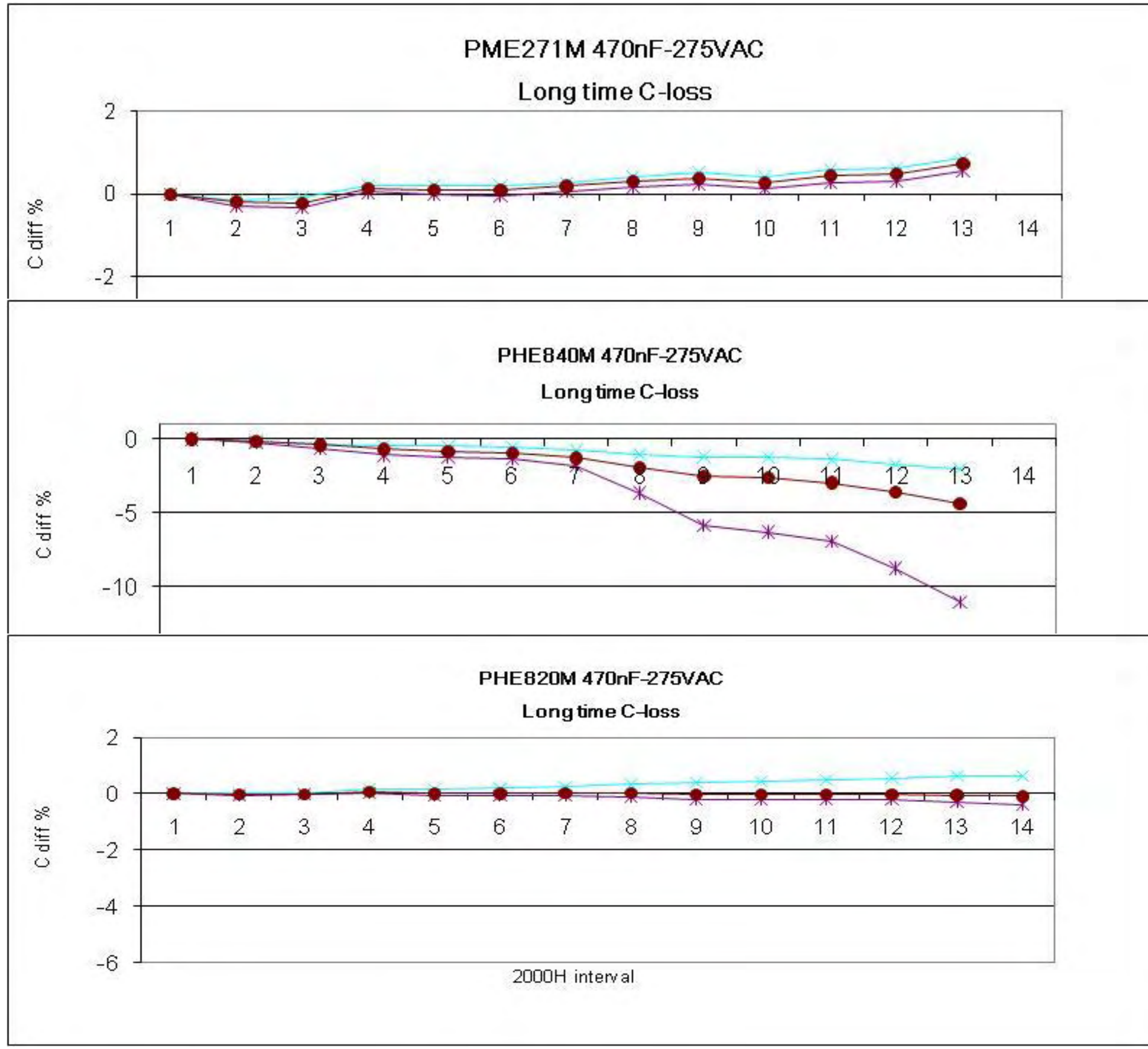
Normal mains connected (240 VAC)

Each x-axis point means 2 000 hours elapsed time (13 x 2 000h = 26 000h ≈ 3 years)

Note: Y-axis scales vary!

% Change in Capacitance:

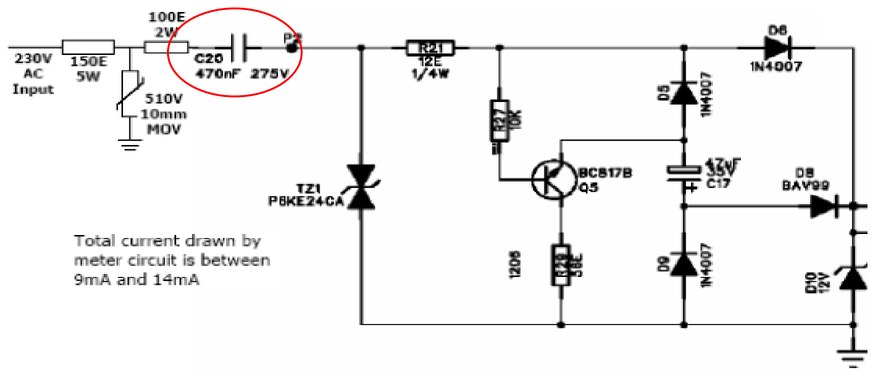
- Minimum negative
- Average negative
- Maximum negative



Capacitors in Series with Mains

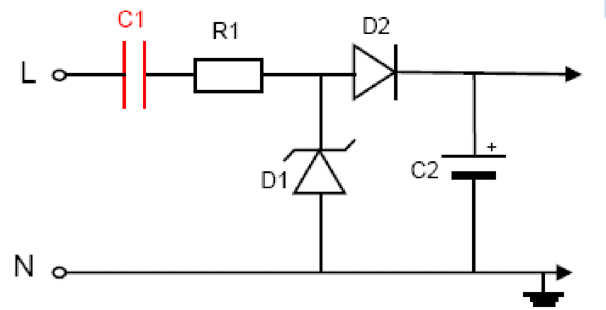
Capacitor Function:

Capacitors are sometimes used in voltage dividers, called also capacitive power supplies, which is a simple way to power certain circuits directly from mains
Typically: 10-820nF / 275 – 300Vac



- Capacitors are used <u>in series</u> to the line before Zener diodes
- The application often requires relatively stabile capacitance value during long life time, even up to 15 year life
- This application <u>does not need</u> a X2 capacitor, but often they are used

EMI Suppression Capacitors
In- Series with mains



Operating Voltage	Series	Safety agency approvals?	Max. Temp ºC	Min. µF	Max. µF	Dielectric	Self healing?	Comments
275VAC	PME271M	X2	110	0.001µF	0.6µF	Impregnated Paper	Yes	Vacuum impregnated paper gives the best long-term stability
300VAC	PME271E	X1		0.01µF	0.22µF			
440VAC	R47	X2, X1		0.0047µF	2.2µF	Polypropylene		2-section series construction
520VAC	R47 (520V)	X2	85	0.0047µF	2.2µF			
275VAC	PHE820M		100	0.01µF	2.2µF	Polyester		
300VAC	PHE820E							
300VAC	R60 3	No	105	0.15µF	6.8µF			
230 and 250VAC	R75 2 - R75 L			0.01µF	10µF	Polypropylene		Single-section with humidity protection

- New KEMET **F862** **Series**

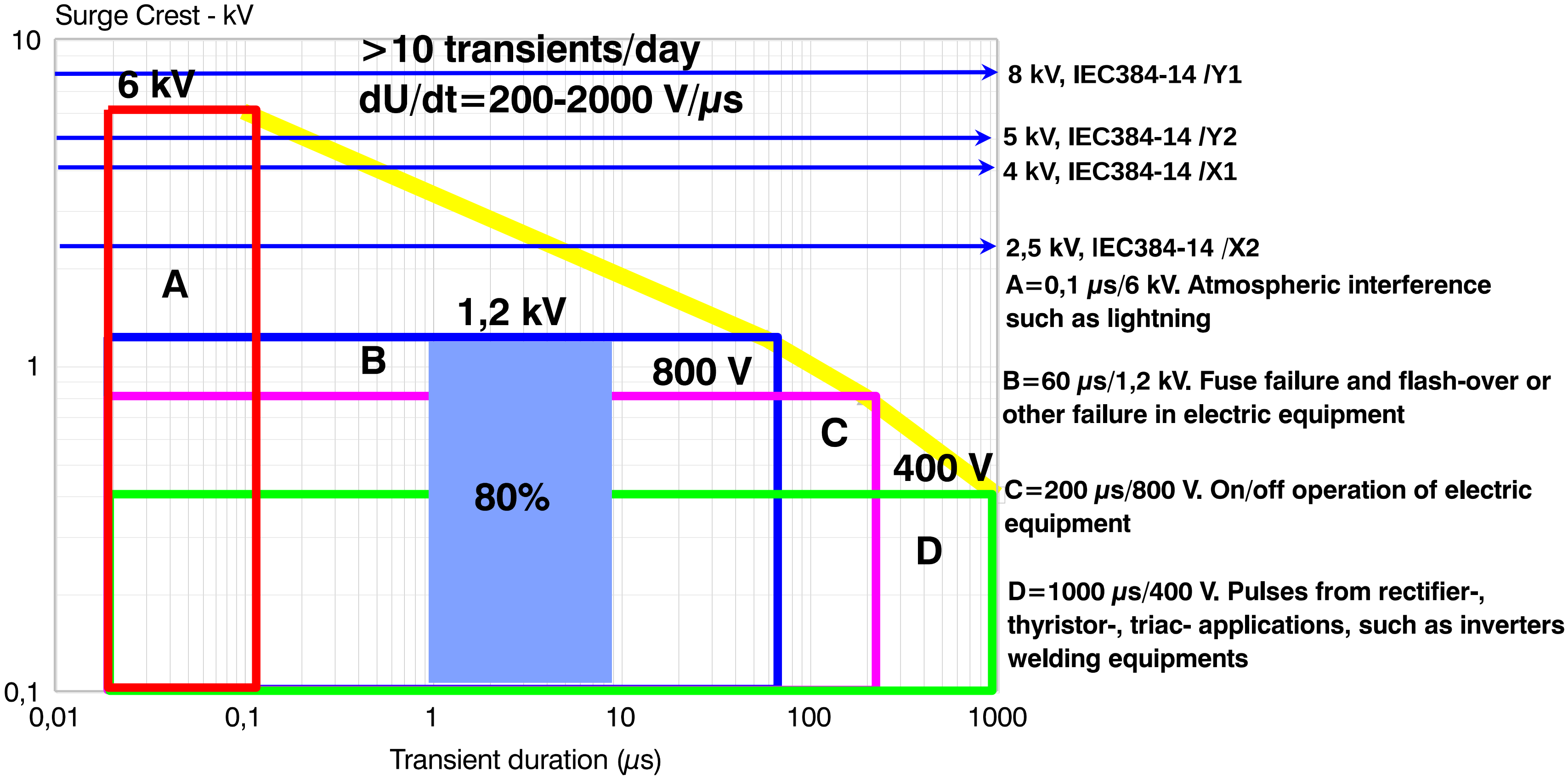
Catastrophic Failures

- **Fire as a consequence of dielectric break-down.**
- **Fire as a consequence of bad contact between wire, end spraying and electrodes.**
- **Short circuit of Y capacitor and a risk of exposing someone to dangerous electrical shock.**

Surges on the Mains Network, UNIPEDE report

The Capacitance Company KEMET CHARGED.

Field measurements have been behind the determination of test voltage levels for different capacitors

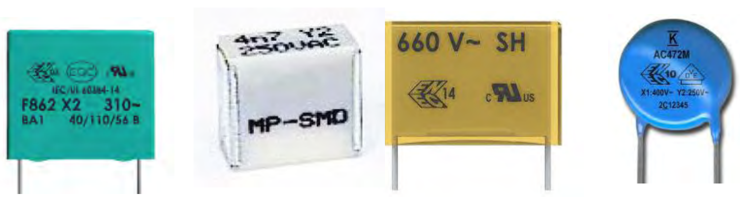


UNIPEDE = Union of Producers and Distributors of Electric Energy

EMI (Safety) Capacitors

Because of the potential for injury the various safety agencies provide testing and recognition for X and Y capacitors.

Region	Description	Specification
Europe	Across-the-line EMI Filter	EN/IEC 60384–14
USA Canada	Across-the-line EMI Filter	UL 60384–14 and CAN/CSA–E60384–14
China		GB/T 14472



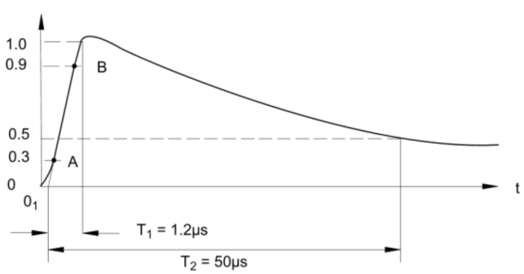
Film Paper Ceramic

"Safety agency approvals do not insure product performance. Simply stated, equipment may fail after a line transient provided it fails ***safely***"

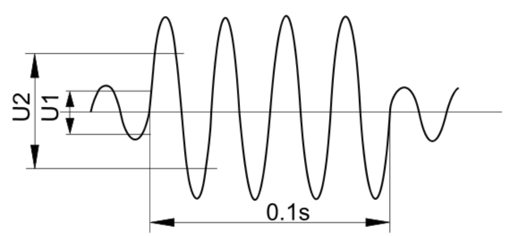
EMI Capacitors

X & Y Sub-Class Capacitors

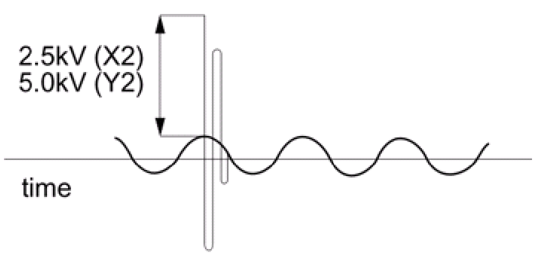
Sub Class	Peak Voltage Test (KV) C ≤ 1uF	Peak Voltage Test (KV) C ≥ 1uF	Insulation / Application
Y1	8	-	Double or Reinforce Insulation
Y2	5	-	Basic or Supplementary insulation
X1	4		High Pulse Applications
X2	2.5		General Purposes



Impulse



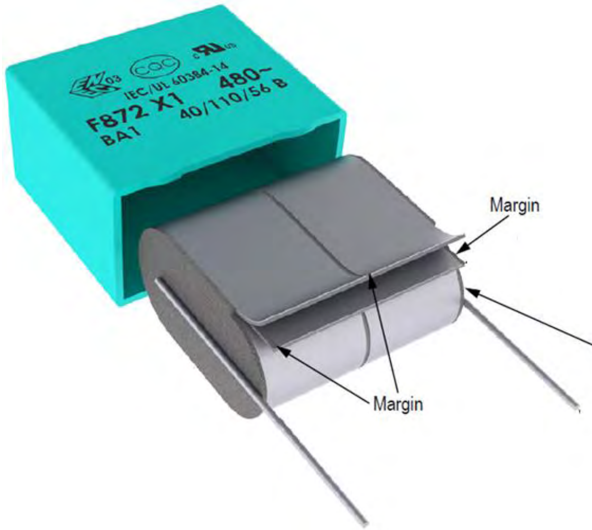
Endurance

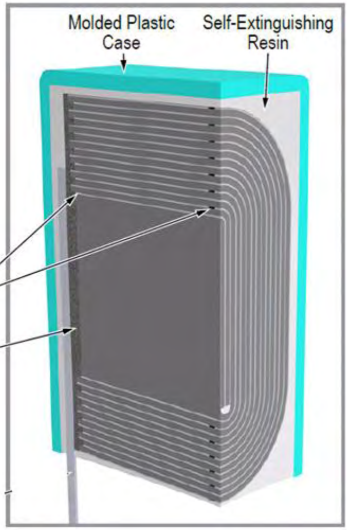


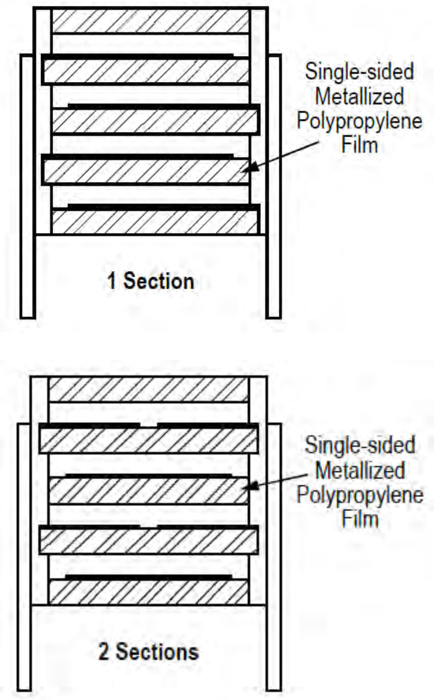
Active Flammability

EMI Safety Capacitors

X & Y Film (Polypropylene)







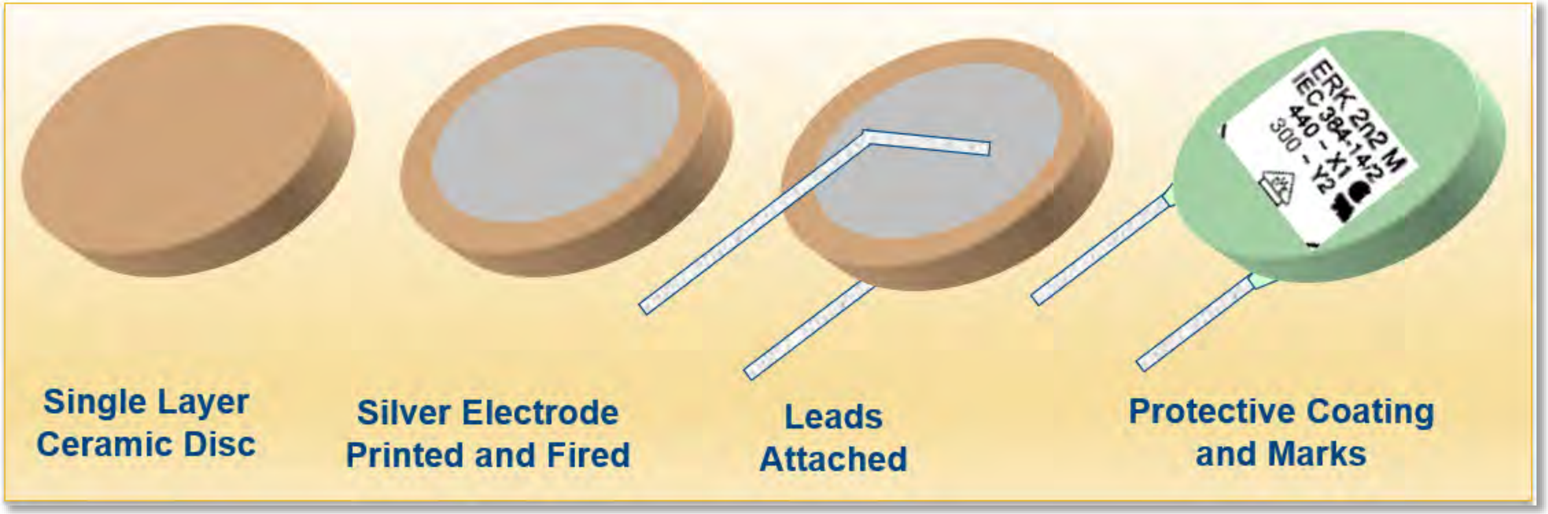
- Zn/Al Metallization (R: 10 to 20 Ω/sq)
- Vac:275, 310, 330, 440, 600, 760
- Available as AEC Q200 Certified (85°C / 85% R.H., 1,000h)

- Very Good Self-Healing (PP)
- Resistant Against Voltage Spikes
- Very Low Dissipation Factor & Dielectric Absorption

EMI Safety Capacitors

Single Layer Ceramic Disc Capacitors

- Compact
- Low cost
- Ceramic is not self-healing
- Y5U dielectric: relatively unstable capacitance
  - Temperature dependence, aging and AC/DC voltage bias

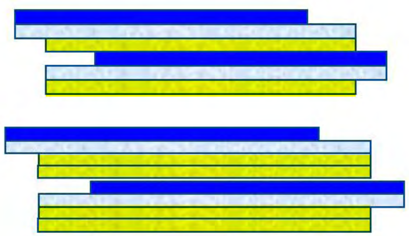


EMI Safety Capacitors

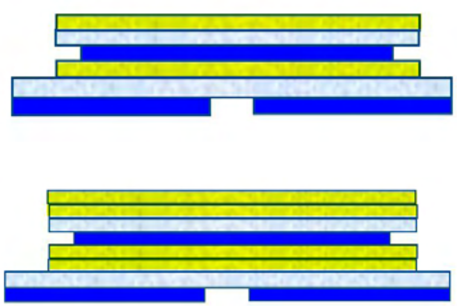
X & Y Metallized Impregnated Paper

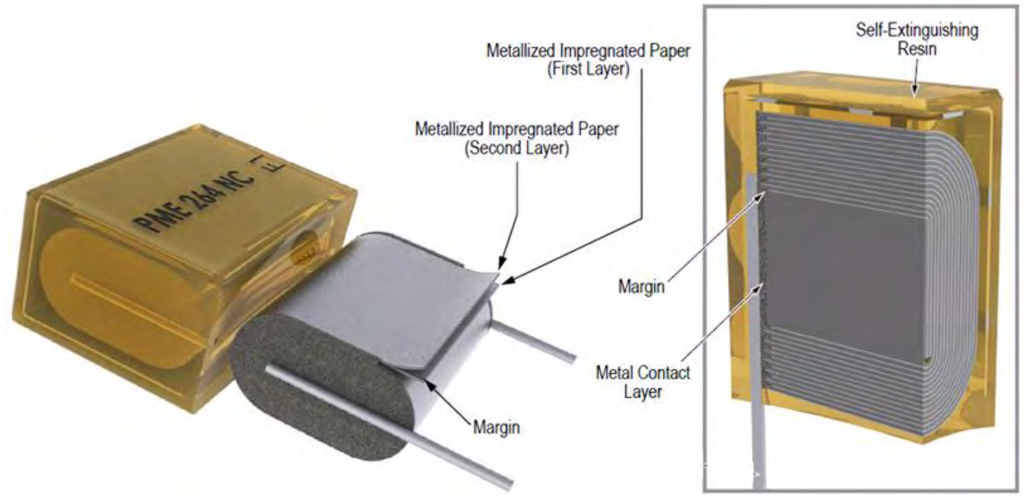
Multi-Layer Impregnated Dielectric

Single Design



Series Design



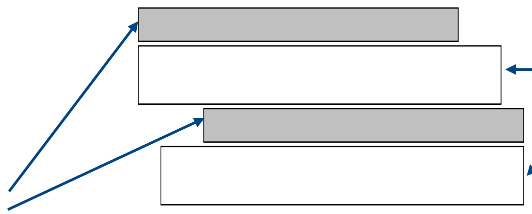


- High Dielectric Constant
- Excellent Self-healing
- High dv/dt (Transient Handling Capability)
- High Ionization Level (Resin)
- Stable Capacitance in Harsh Environment & Voltage Conditions.

- Zn Metallization (R: 2.5 Ω/sq.)
- VAC: 275, 300, 480, 500, 660

Metallized Film

Self-Healing

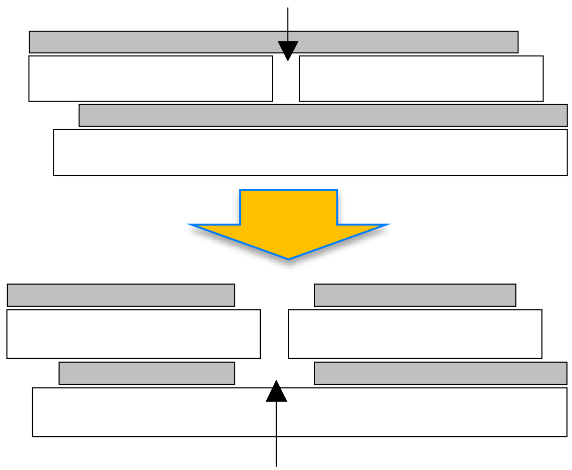


Dielectric
1µm

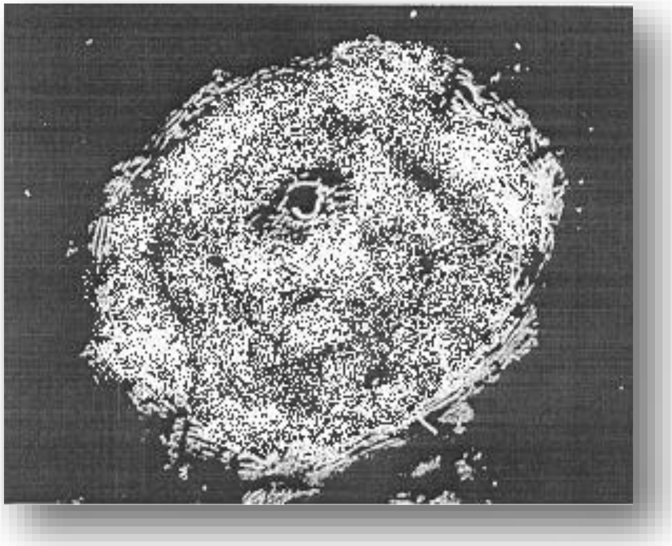
Metal layer
< *0.02µm*

- Metallized Film
  - Smaller Size
  - Higher C Value
  - Higher Reliability
  - Lower Cost
  - Lower Weight

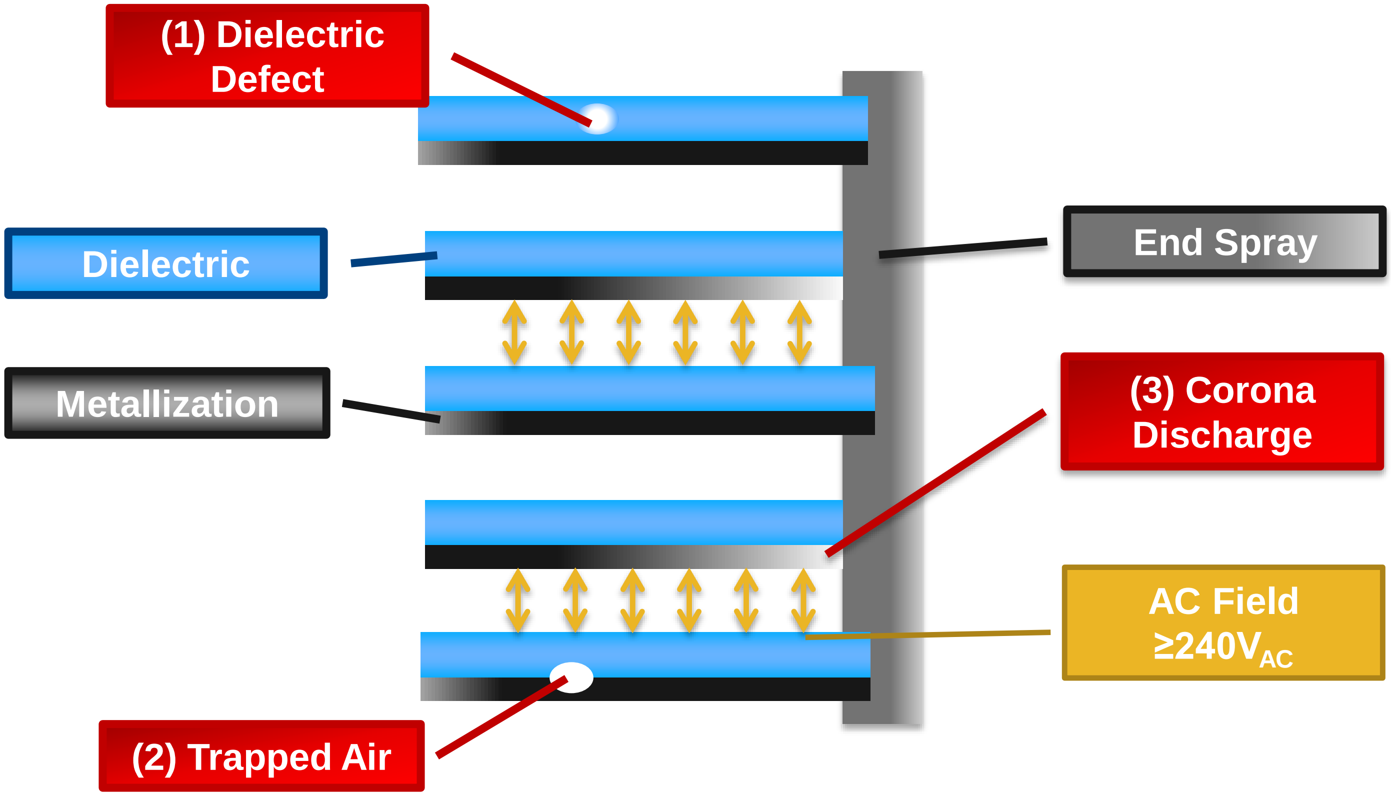
Breakdown Channel
Weak Point



Metallization Evaporates
The Insulation Is Restored

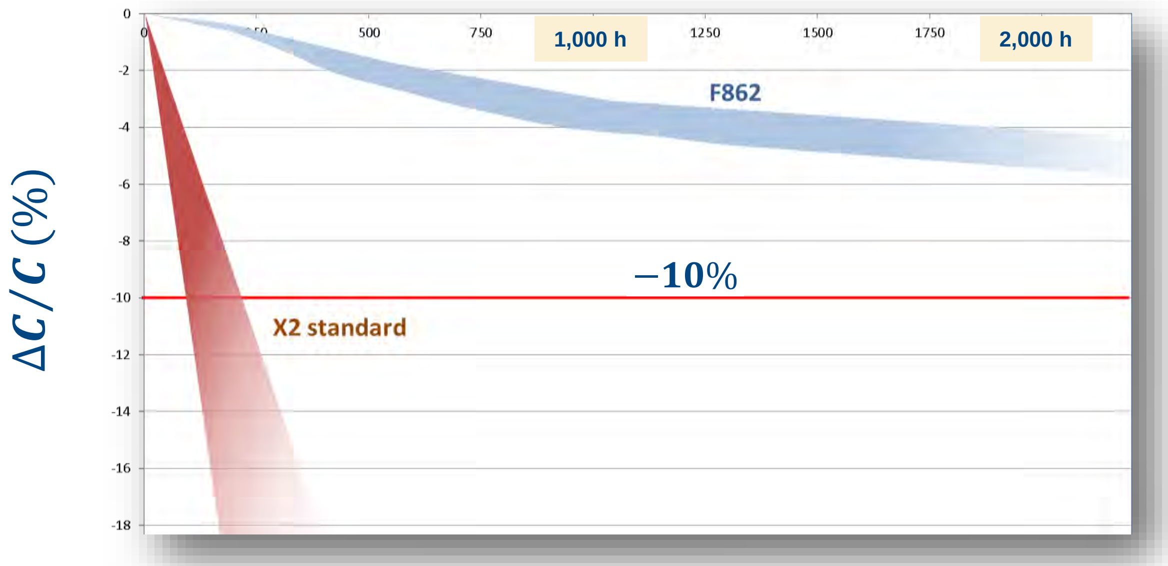


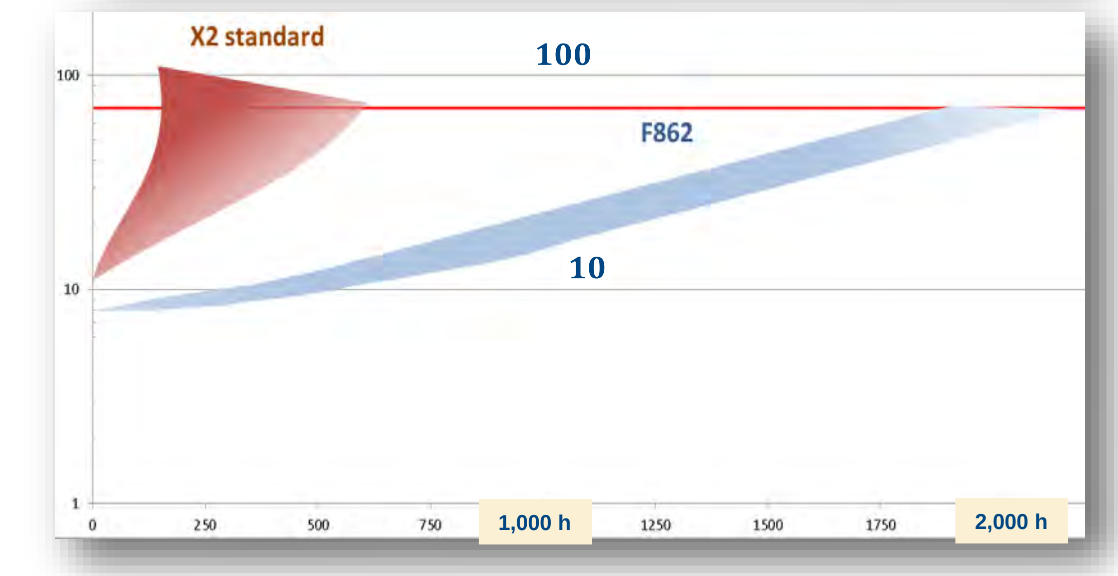
Film Capacitance Loss



Film Capacitance Stability

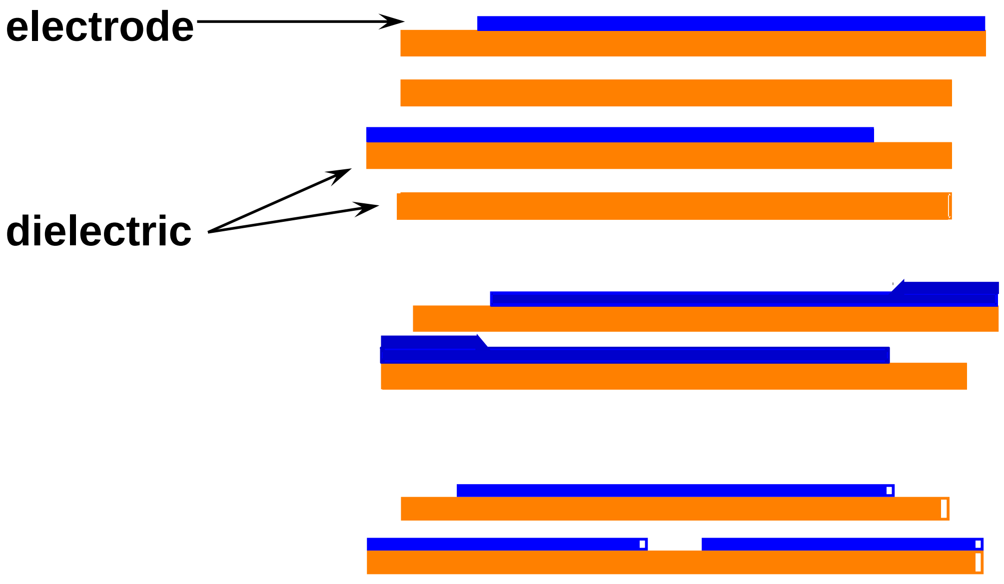
Example: Capacitance & DF Change Trend
THB Test (85/85, 1,000 Hours)





Protection against severe ambient conditions is critical for Heavy Duty and In Series with the Main Applications

Typical Winding Structures



Impregnated metallized paper (Ex. PME271)

Heavy edge metallizing metallized plastic film (Ex. R46 and PHE840M/E)

Series design metallized plastic film (Ex. PHE820)

Typical Data

	Ceramic	PP film	PET film	Impregnated paper
Capacitance max. (µF)	0.022	40.0	2.2	0.68
Dielectric constant	High	2.2	3.3	5.3
Dissipation factor (%, 1kHz)	3.0	0.05	0.5	0.8
Insulation resistance (GΩ)	80	400	250	100
Max dU/dt (V/µs)		100	100	1000
Dependence on temperature and voltage	High	Low	Low	Low

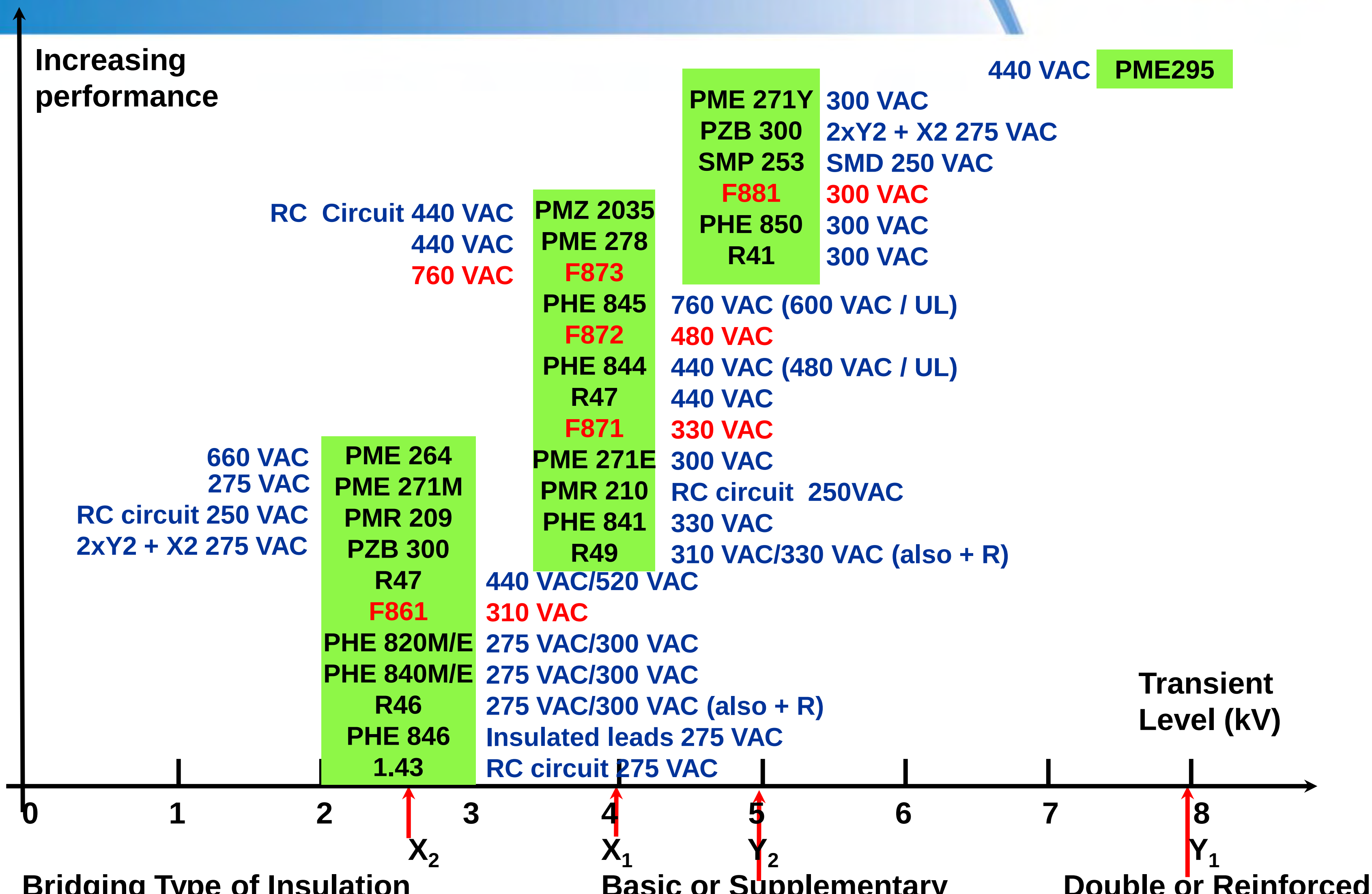
Main Differences Between Technologies

The Capacitance Company KEMET CHARGED.

- **Metallized film and impregnated paper capacitors are self-healing and will survive a partial breakdown.**
- **Ceramic and film/foil capacitors can not recover from a partial breakdown.**

KEMET EMI Capacitor Range

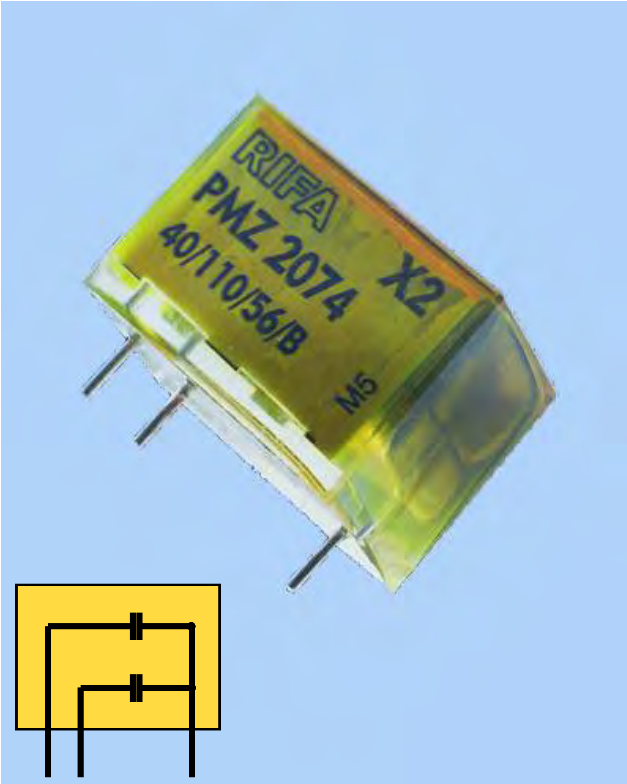
Red Products are New KEMET Series



One WORLD *One Brand* *One Strategy* *One Focus* *One Team* **One KEMET**

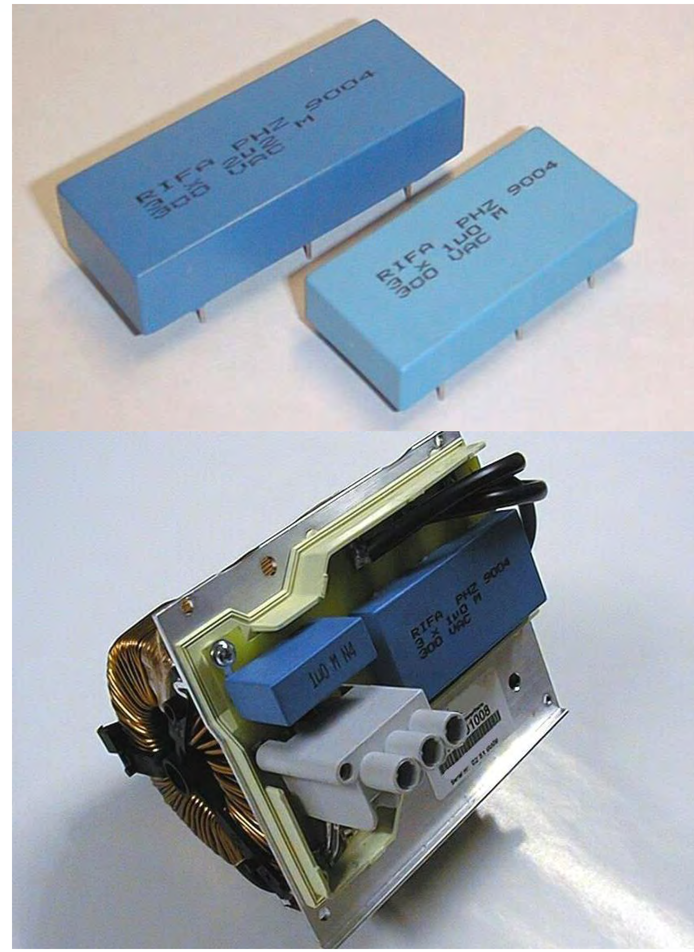
Customised: PMZ2074

- **Application: Ignitors**
- **Metallized paper EMI suppressor, class X2**
- **Double capacitor; two capacitors in series**
- **Rated voltage 275 VAC**
- **Capacitances:**
  - 150 + 47 nF
  - 220 + 82 nF
  - 220 + 100 nF



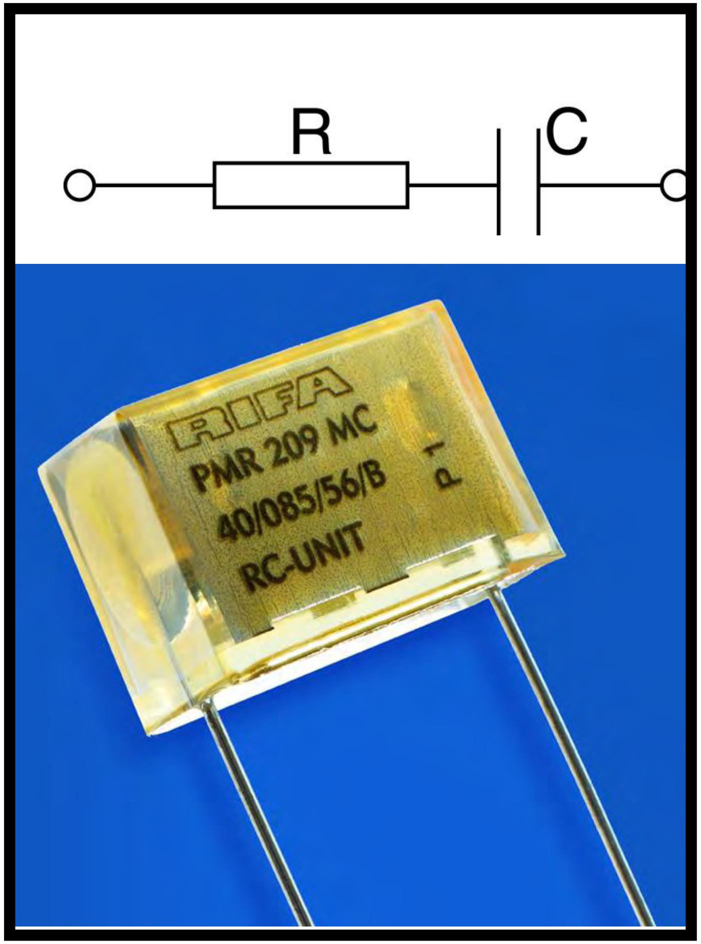
Customised: PHZ9004

- **Low profile triple capacitor, three separate capacitors in the same box**
- **Metallized polypropylene EMI suppressor, X2 applications, 300 VAC**
- **Capacitances**
  - 3 x 1.0 µF
  - 3 x 2.2 µF
  - Other values possible!

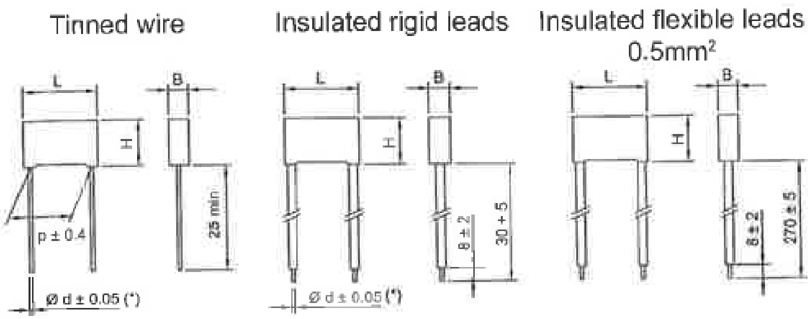


RC units
PMR205, PMR209, PMR210, PMZ2035

- Metallized Paper capacitor with integrated resistor
- Bipolar, suitable for DC and AC operations
- One component instead of two
- Small dimensions
- Outstanding reliability, high dU/dt capability and excellent self-healing properties



- Separate Polypropylene capacitor and resistor
- 10 nF to 1 µF / 1000 Ω - 10 Ω
- Series without safety approvals (250 Vdc/160 Vac – 630 Vdc/220 Vac)
- 275 Vac with X2 Class approval

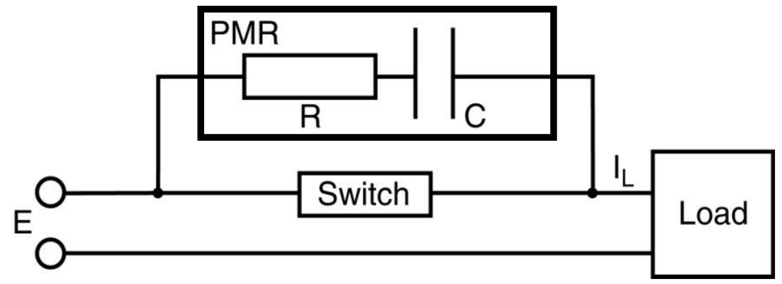


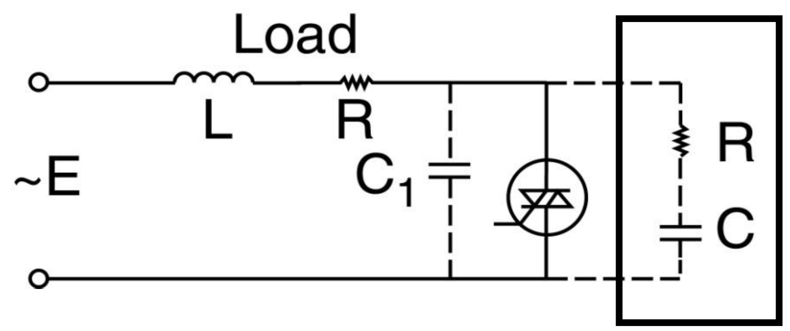
All dimensions are in mm

RC units
PMR205, PMR209, PMR210, PMZ2035, 1.43

Designed for use in applications for:

- **Spark suppression during switching**
- **Transient suppression for protection of low-frequency thyristors and triacs**
- **dU/dt limitation in thyristor and triac low-frequency snubber circuits**





Why KEMET EMI Suppression Capacitors?

The Capacitance Company KEMET CHARGED.

The main arguments for using KEMET EMI suppression capacitors are quality and performance and this is what we are selling:

- The highest possible safety regarding active and passive flammability.
- Excellent self healing properties
- Good resistance to ionization
- High dU/dt capability
- Meets the most stringent IEC humidity class, 56 days
- Outstanding reliability in continuous operation
- Small dimensions
- Meets or exceeds various safety standards: EN/IEC 60384-14, UL1414...
- Is the reference for benchmarking

These benefits are the result of more than 60 years of dedicated research and development and are our customer's safety insurance free of charge.

Comparison of Dielectric Materials for EMI Capacitors

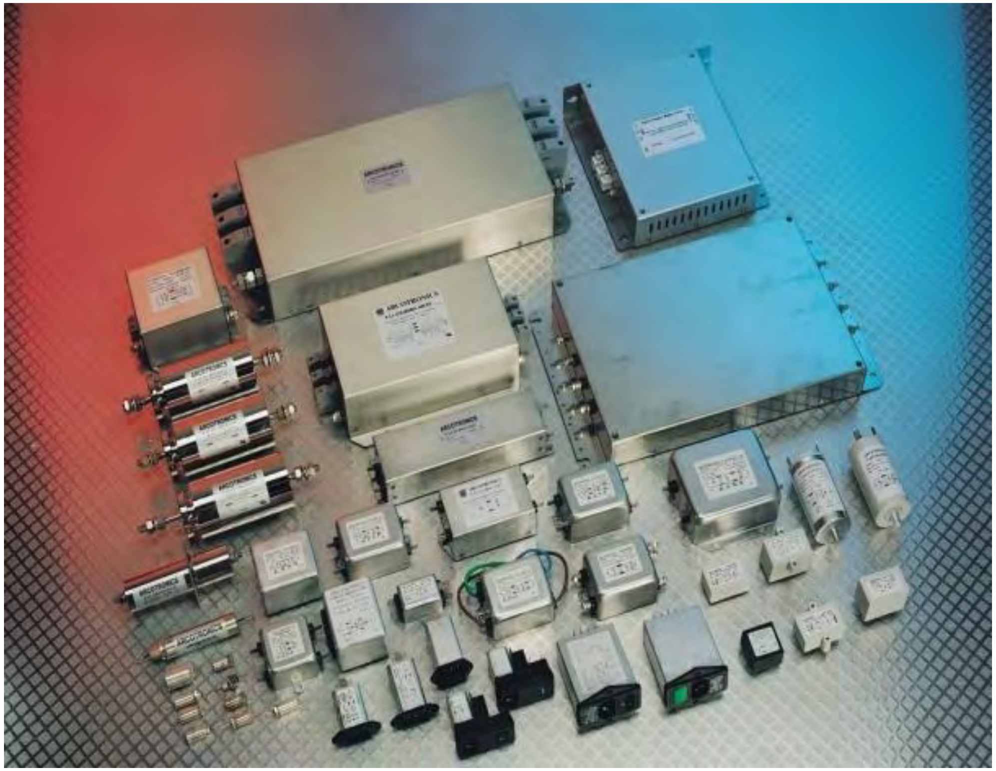
		MP	PP	PET	Ceramic
Transient capability		+++	+	+	–
Self healing capability		+++	++	+	– –
dU/dt		+++	+	+	+
Temperature	Range	+++	+	++	+++
	Stability	++	+++	++	–
	Soldering	+++	+	++	–
Reliability/Safety		+++	+	+	+
Performance/Volume		+++	++	+	+
Component price		–	+++	++	+++
Rating		22	15	13	4

KEMET EMI Filters

General catalogue articles

Type	Ratings	Config.	Elements
Power feed through	16-800A, 250-440Vac	Pi,C	film, toroids
Small signal F/T	0.5-16A, 50-630Vdc	Pi,T,L,C	film,cer, toroids
Industrial	1-2500A, 250-600Vac	various	film, inductors
PCB	0.5-16A, 250Vac	various	film, toroids
Screen room	1-225A, 277Vac, 600Vdc	various	film, toroids
Cylindrical	6-16A, 275Vac	various	film, toroids
IEC Inlet	1-16A, 250Vac	various	film, toroids

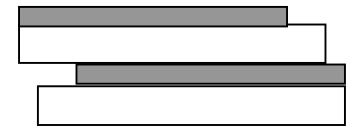
Product Portfolio



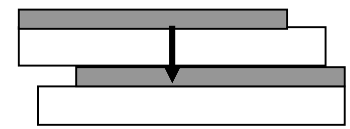
Self Healing

Self-healing

Capacitor's cross section:



In the case of dielectric breakdown, high current flows between the electrodes, through the discharge path:



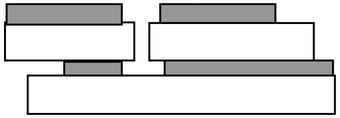
Due to the high current, the dissipated power in the breakdown increases the temperature in the range of thousands of centigrade.

At this temperature, the two electrodes and the dielectric, evaporate as single atoms.

As soon as the temperature decreases, atoms combine with each other making new molecules.

These molecules are mainly gases made of Carbon (C), Hydrogen (H) and Oxygen (O).

Self-healing



After the phenomenon described above, the electric insulation has been restored (high insulation resistance):

In the case of excess Carbon (Carbon not combined with Hydrogen or with Oxygen), the excess amount will be deposited in the area where the breakdown has occurred, lowering the insulation resistance.

If the excess amount is high (high amount of Carbon compared to Hydrogen and Oxygen), Carbon will be deposited as a thicker layer: as a consequence the insulation resistance will be lower.

The dissipated power in the breakdown area after the breakdown depends on this resistance according to:

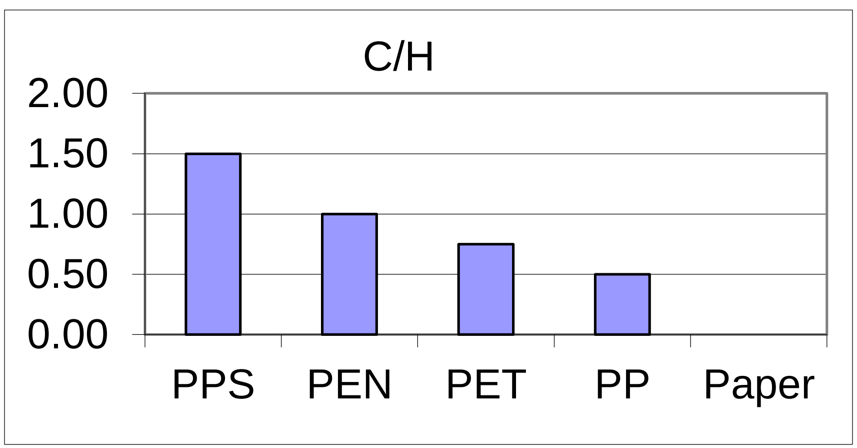
$$P=V^2/R$$

The lower the resistance the higher the power. If the resistance is low enough, the capacitor stays almost as short circuit, and/or the breakdown continues to total destruction of the capacitor.

Self-healing

Comparison between different materials:

FILM	C	H	O	S	C/H*
PPS	6	4	0	1	1,50
PEN	14	10	4	0	1,00
PET	10	8	4	0	0,75
PP	3	6	0	0	0,50
Cellulose	5	10	5	0	≈ 0



*** After all available Oxygen (O) in the Polymer has been consumed (combined with C to CO). Large C/H ratio means high amount of conducting Carbon**

The graph shows what follows:

- **the worst material is PPS;**
- **the best material is Paper, PP of films;**
- **PET is better then PEN.**

Electronic Components
KEMET
CHARGED.®

EMI Core and Flex Suppressor®

Design and Characteristics

EMI Cores and Flex Suppressor®

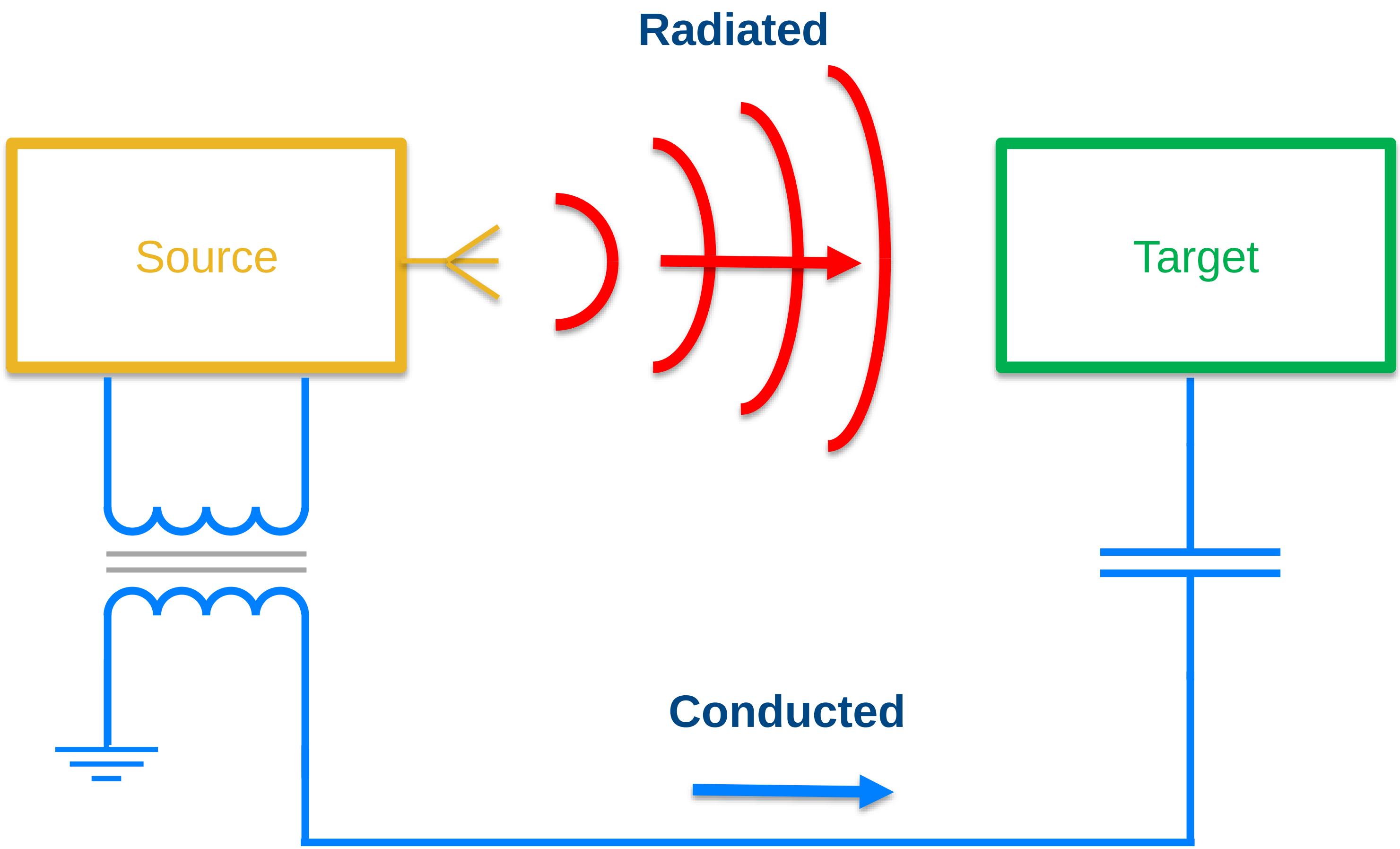
Electronic Components KEMET CHARGED®

EMI Cores

Flex Suppressor®

Electromagnetic Interference

Radiated vs Conducted



Electronic Components KEMET CHARGED.

EMI Cores

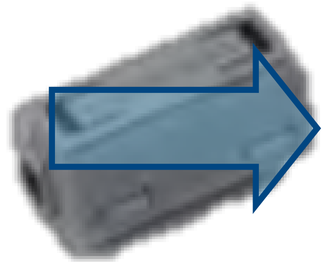
Design and Characteristics

EMI Filtering

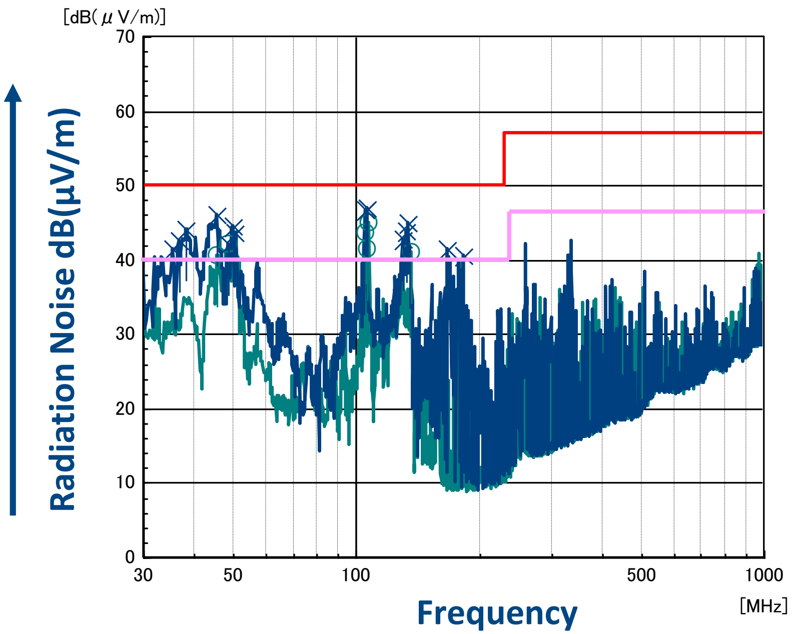
Effect of Using EMI Suppression

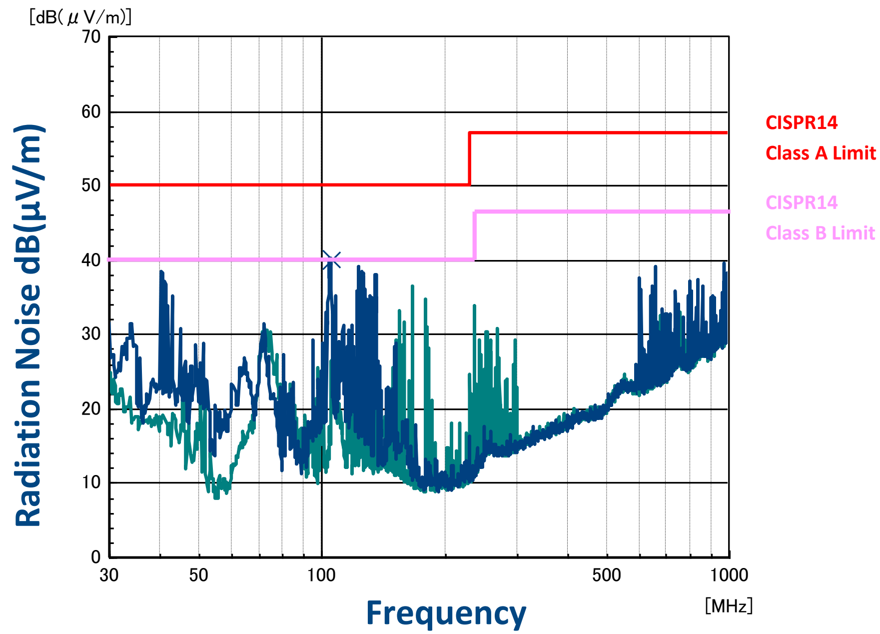
An EMI core is a passive electric component used to suppress high frequency noise in electronic circuits

Before filtering



After filtering





EMI Cores

Types

Solid

Snap-On

“Snail-Shaped”

Cables connect to devices act as an antenna for the noise

EMI Core employ the dissipation of high frequency currents in a ferrite ceramic to build high frequency noise suppression devices

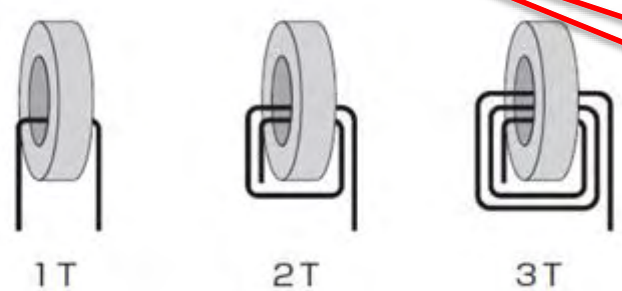
- Available for round and flat cables
- Nickel-Zinc (NiZn) for FM band range
- Manganese Zinc (MnZn) for AM band range

EMI Core

Defining Parameters

Electronic Components KEMET CHARGED.

- *No inductance, no rated voltage needed*
- Round or flat cable
- Mounting versions
- Shape and dimension
- Diagrams shows impedance over frequency
- Number of turns can increase the impedance



*Number of lead wire wound outside the core + 1
= Number of read wire passes through the inner hole of the core
= Turn count

Fig.1 How to count turns

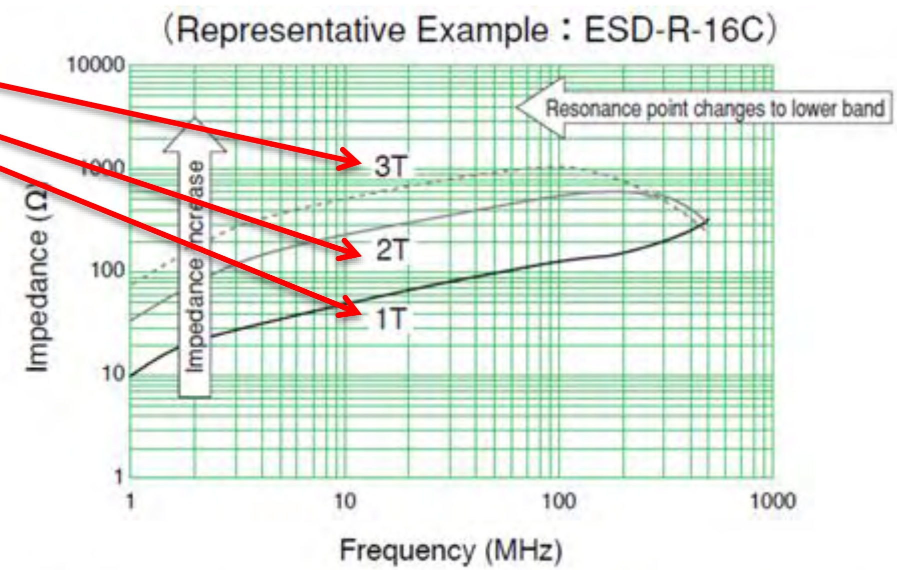


Fig.2 Relationship between impedance and turn counts

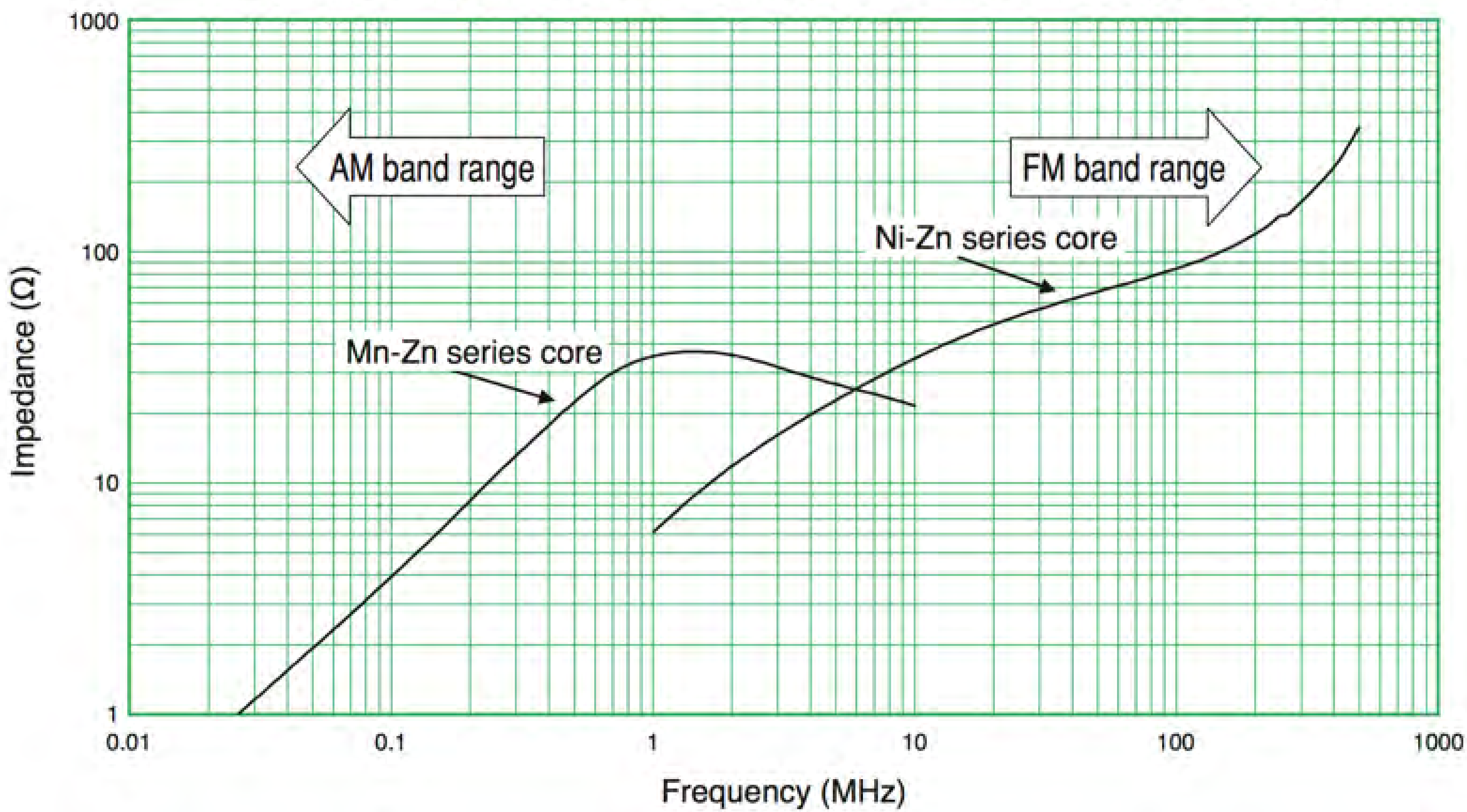
EMI Core

Frequency Range

Depends on the material

Mn-Zn series vs Ni-Zn series |Z|-f Characteristics (representative example)

(measurement condition: measured with same-dimension ring core)

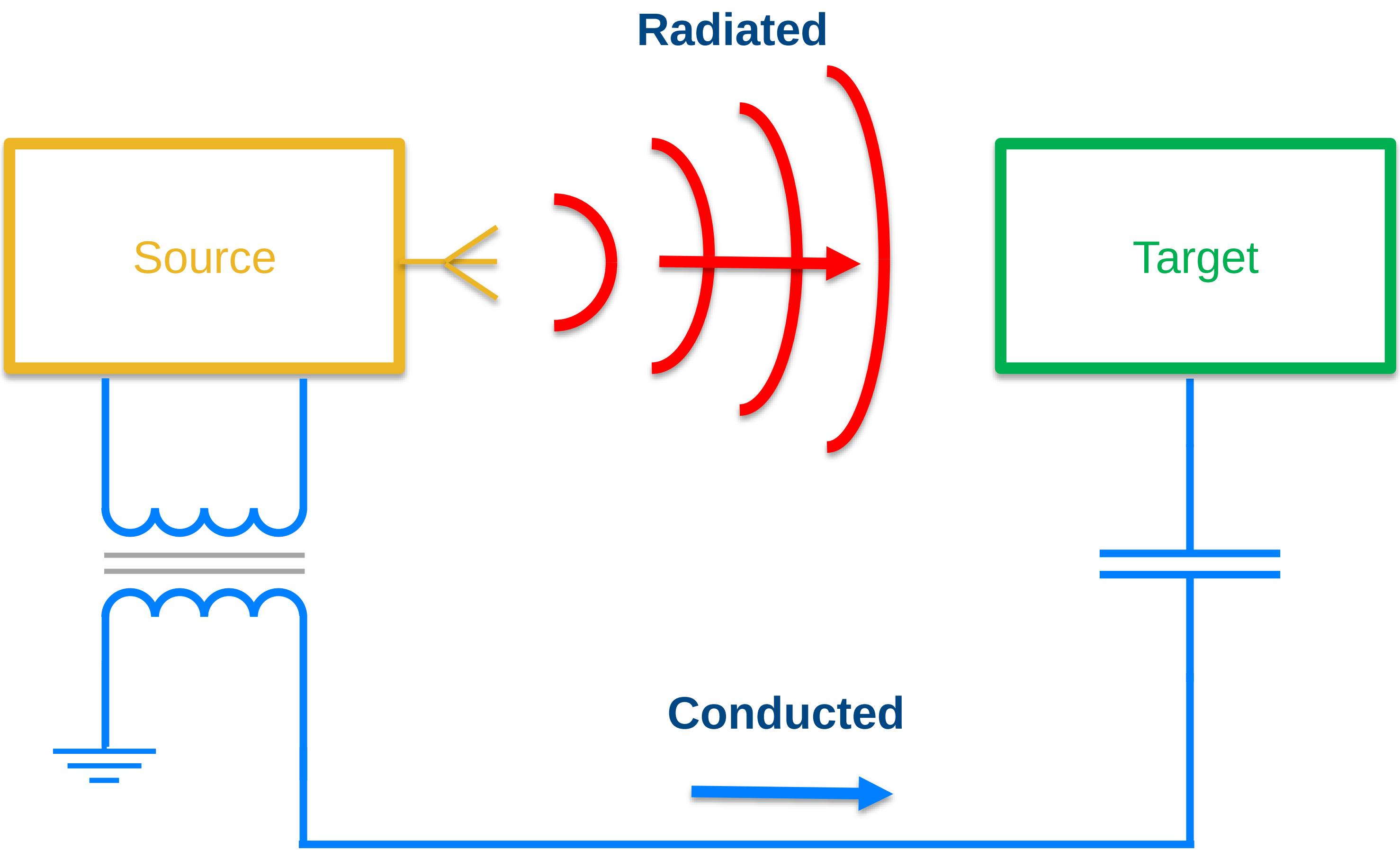


Flex Suppressor®

Design and Characteristics

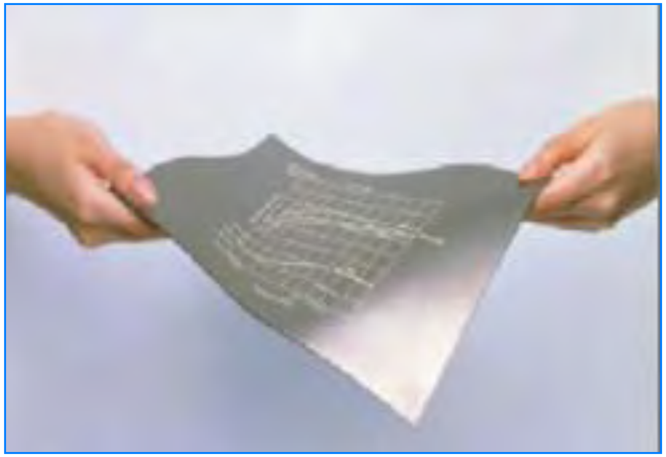
Electromagnetic Interference

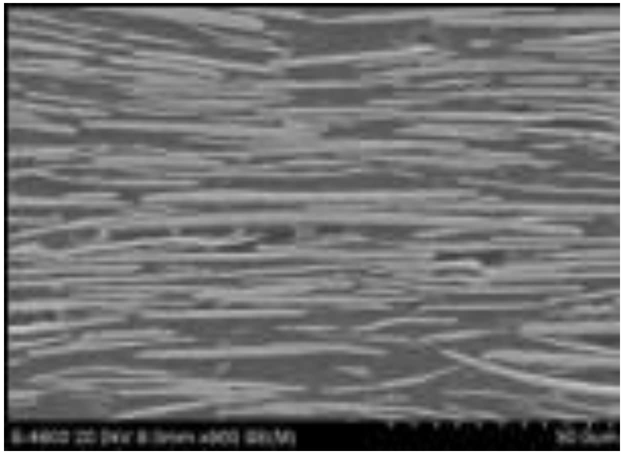
Radiated vs Conducted



Flex Suppressor® Sheets
Overview

- **Definition**
  – A flexible polymer sheet with micro-magnetic foils
  – Attenuates or suppresses Electromagnetic and Radio Frequency Interferences (EMI/RFI)
  – It can also be used to improve magnetic signal transmissions and receptions
- **How does it work?**
  – The sheet absorbs the electromagnetic noises and converts them into heat

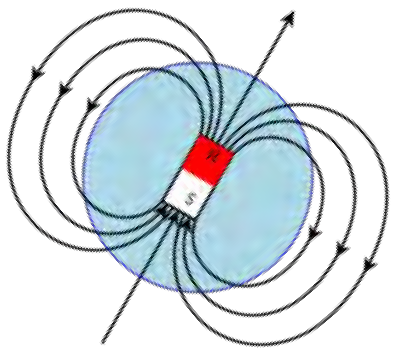




Flex Suppressor®

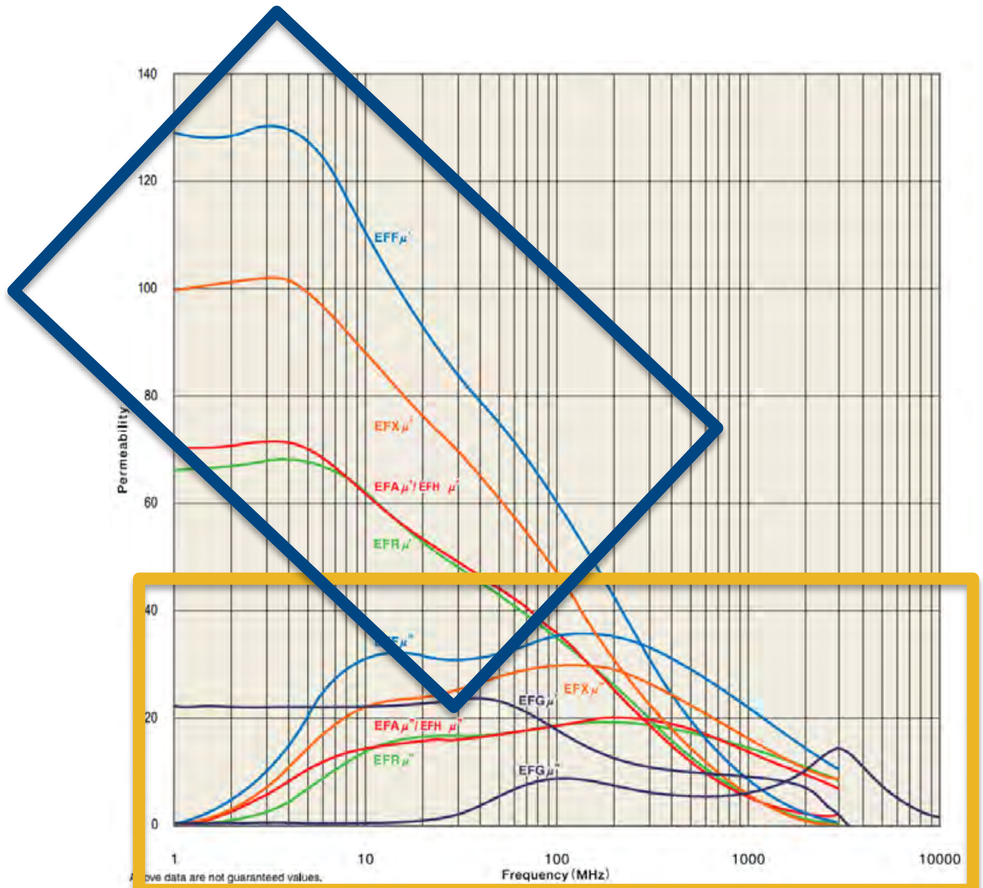
Permeability

- High Permeability (μ) = Strong Magnetic Field
- High μ Materials Absorb EMI
- High μ Absorb and Re-shape Magnetic Fields



$$\mu = \frac{B_0}{H_0}\cos\delta - j\frac{B_0}{H_0}\sin\delta = \mu' - j\mu''.$$

$$\tan\delta = \frac{\mu''}{\mu'},$$



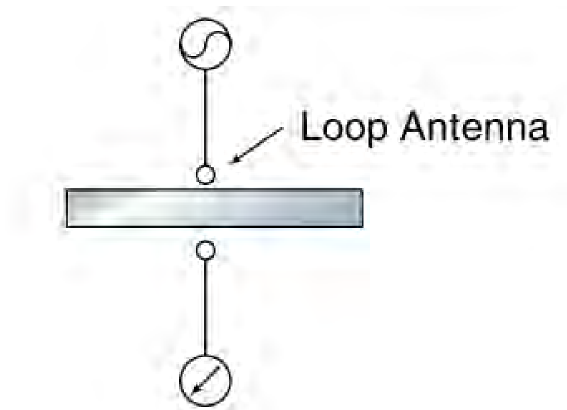
μ` = Inductance

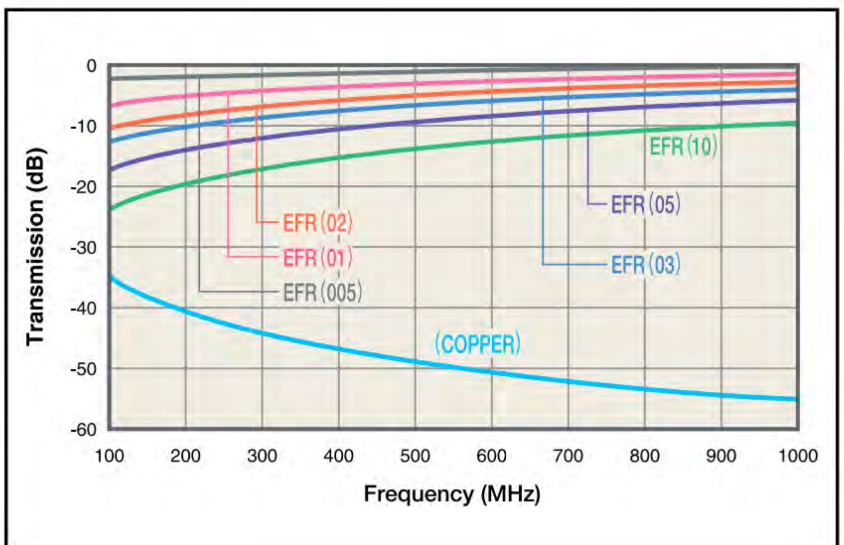
μ`` = Magnetic Impedance (loss)

Flex Suppressor®

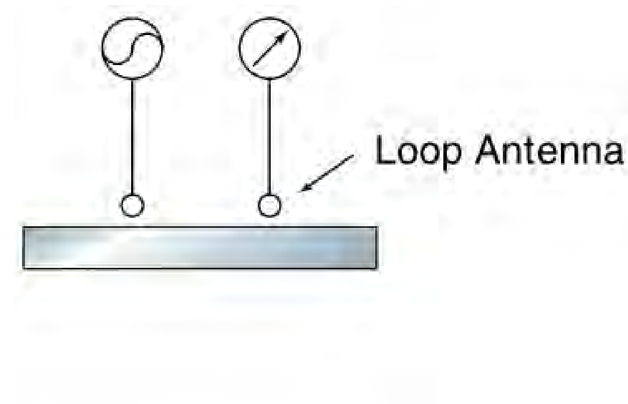
Noise Attenuation

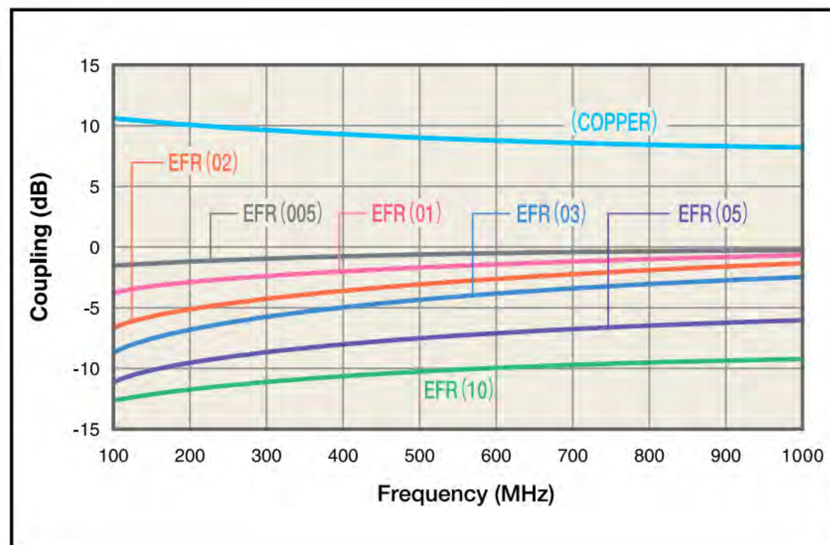
Transmitted Attenuation





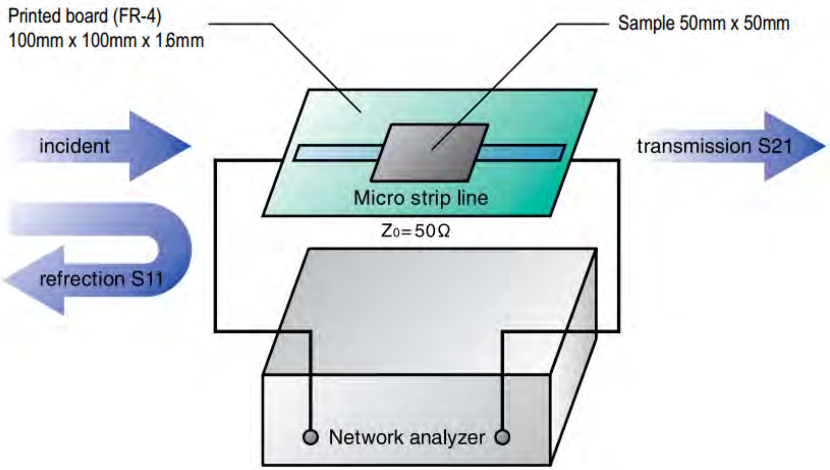
Coupling Attenuation

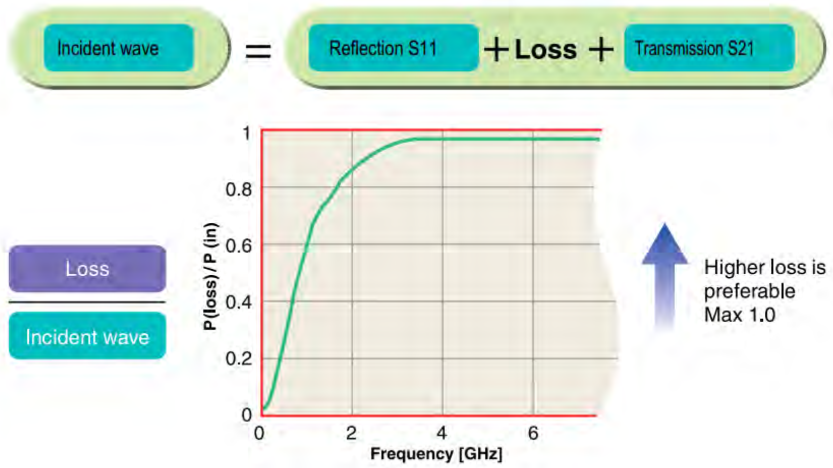


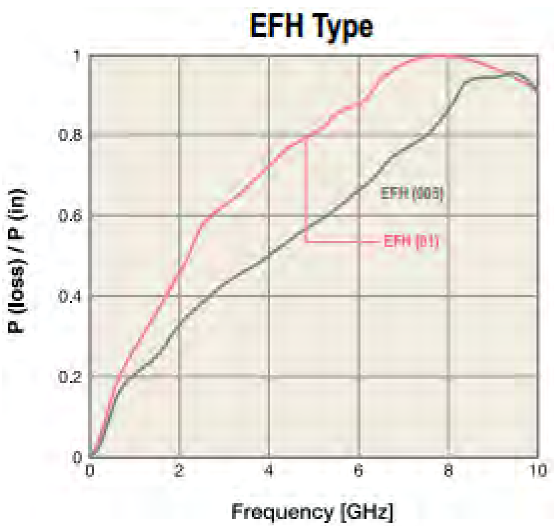


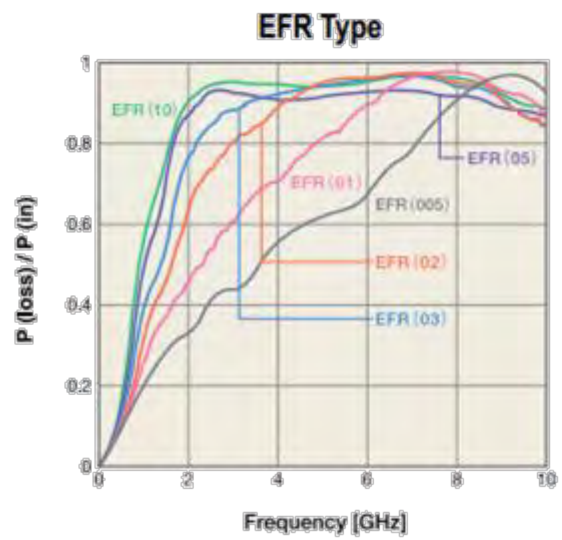
Transmitted Attenuation

Measurement Technique









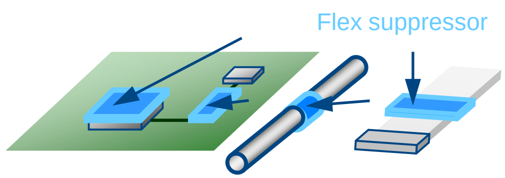
Flex Suppressor® Sheets

Applications

Absorption

For EMI

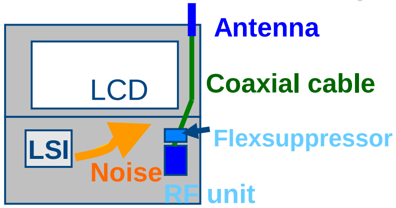
Radiation (for EMI regulation)



Suppression of radiation noise from CPU/GPU, signal line, cable etc.

For De-sense

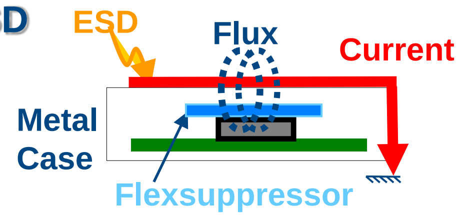
Wi-Fi (for internal interference)



Internal noise is interfering to Wi-Fi receiving sensitivity. Flex-suppressor improves desense.

For ESD

ESD

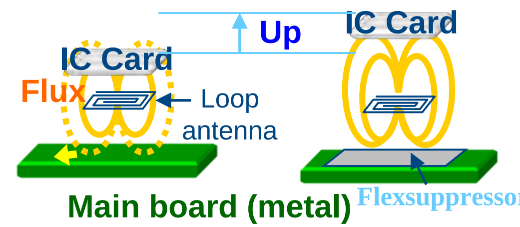


Internal interference caused by ESD is a factor of false operation. Flex-suppressor improves this issue.

Magnetic Shielding

For RFID

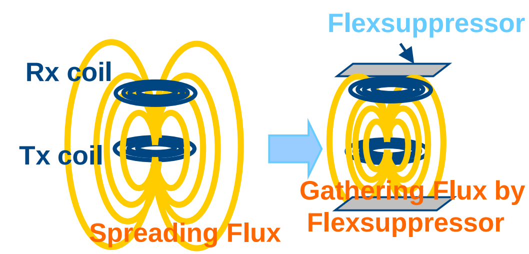
NFC (RFID etc.)



NFC communication distance is enhanced by Flex-suppressor.

For Wireless Charging

Wireless charging

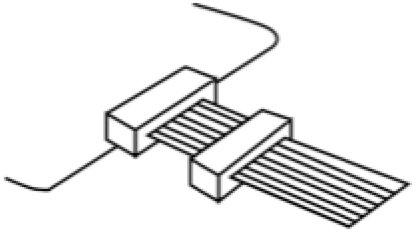


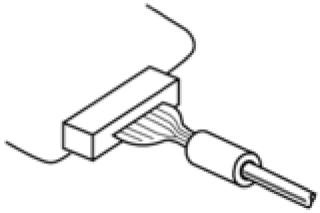
Conversion efficiency is improved by using Flex-suppressor

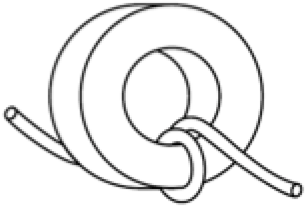
EMI Core

Typical application

- Information and communication devices
- White goods
  - dishwasher, washing machines, microwave, air conditioner, refrigerator
- Location
  - inside systems on cable or wiring harness
  - cable or wiring harness going to PCB
  - around data & power cables







HDMI

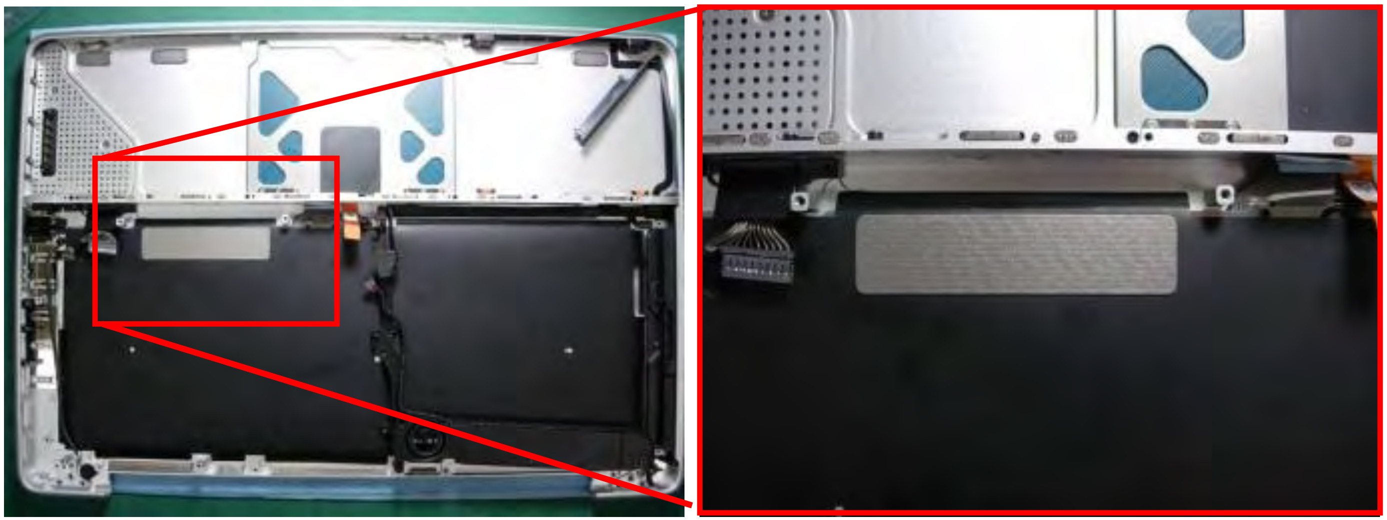
SATA

Cables attached to devices can act as an antenna that radiates noise

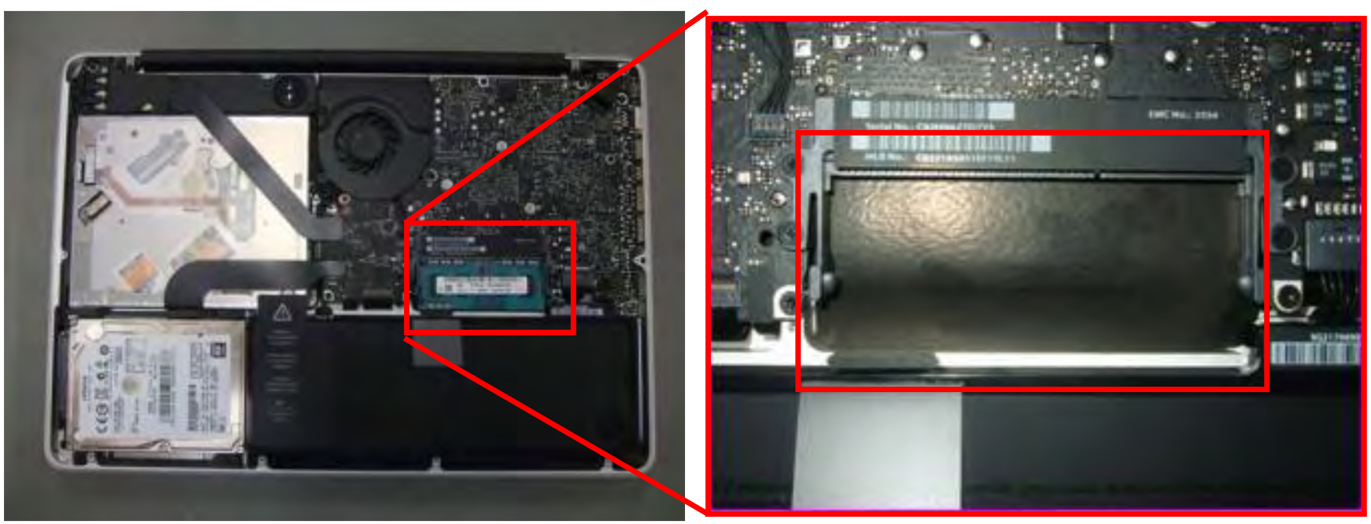
Flex Suppressor® Sheets

Notebook PC DRAM Memory Example

- DDR2-800： Bus clock 400MHz X 6 times



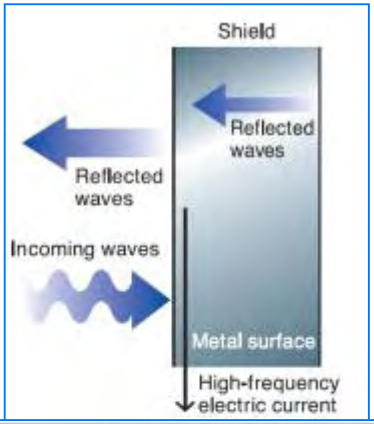
- DDR3-1600： Bus clock 800MHz X 3 times



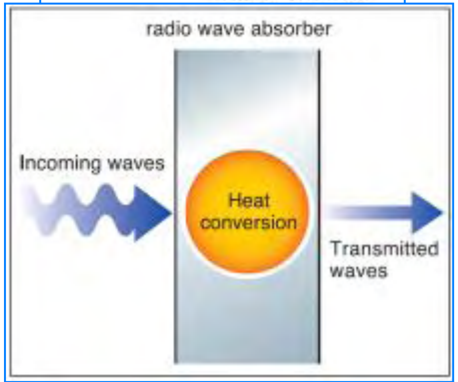
Flex Suppressor® Sheets

Shielding Materials and Radio Wave Absorbers

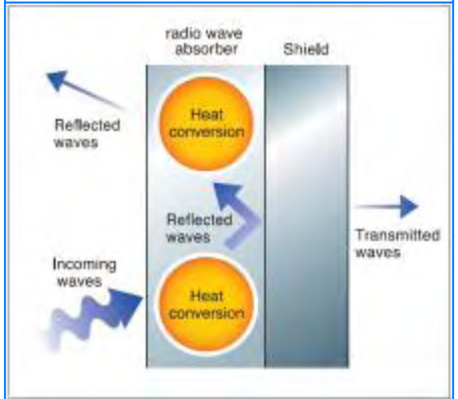
- Shielding materials reflect most of the transmitted waves causing internal interference
  - Typically Metal conductive materials



- Radio wave absorbers prevent reflections and transform the absorbed energy waves into heat



- Shielding materials and radio wave absorbers can be combined to minimize the transmitted and reflected waves of incoming noise signals



Cool Tools
For Purchasing Professionals

The Capacitance Company
KEMET
CHARGED.

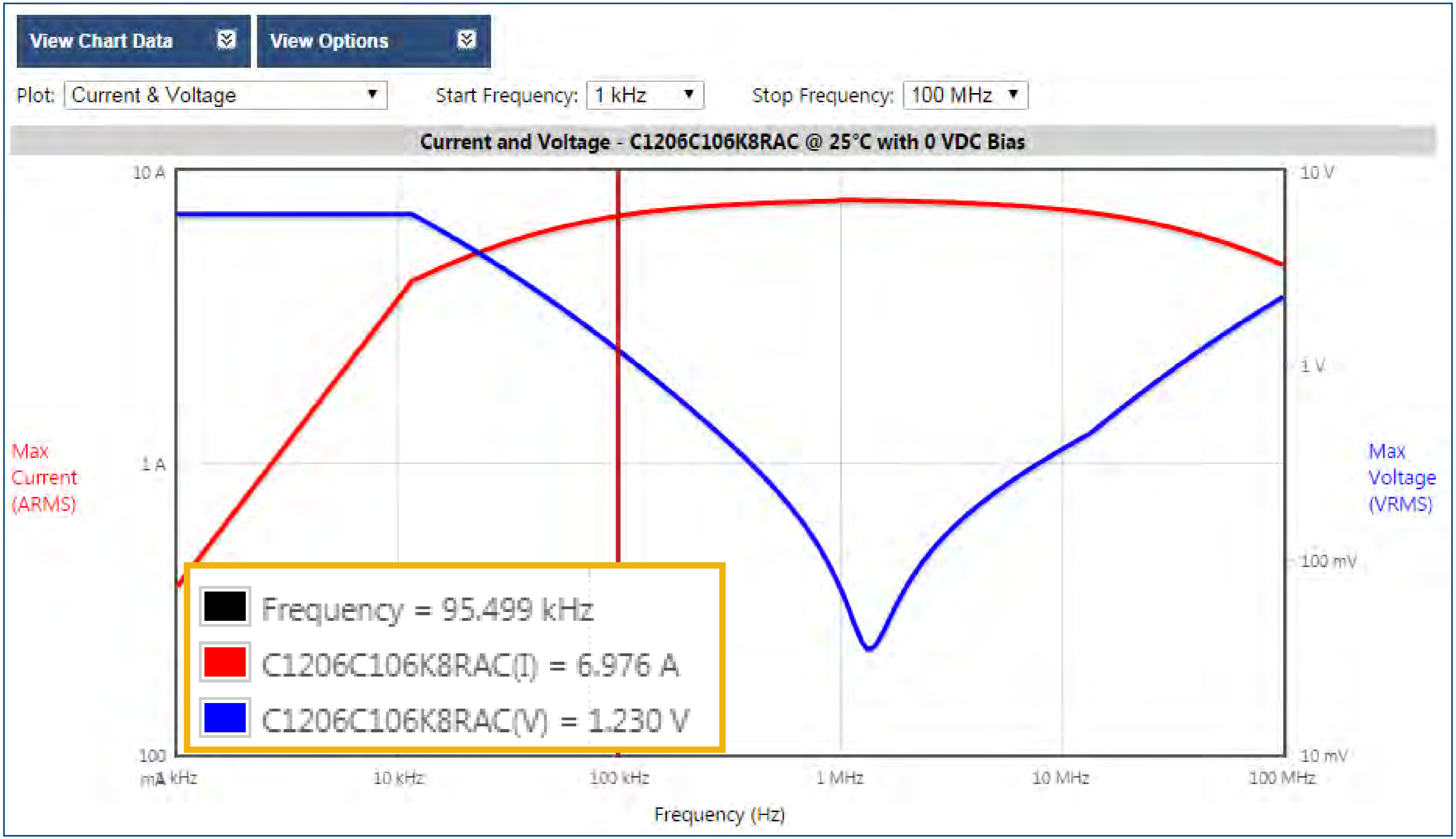
E2BF EASY TO BUY FROM

Capacitor Fundamentals

Ripple Current

Ripple Current

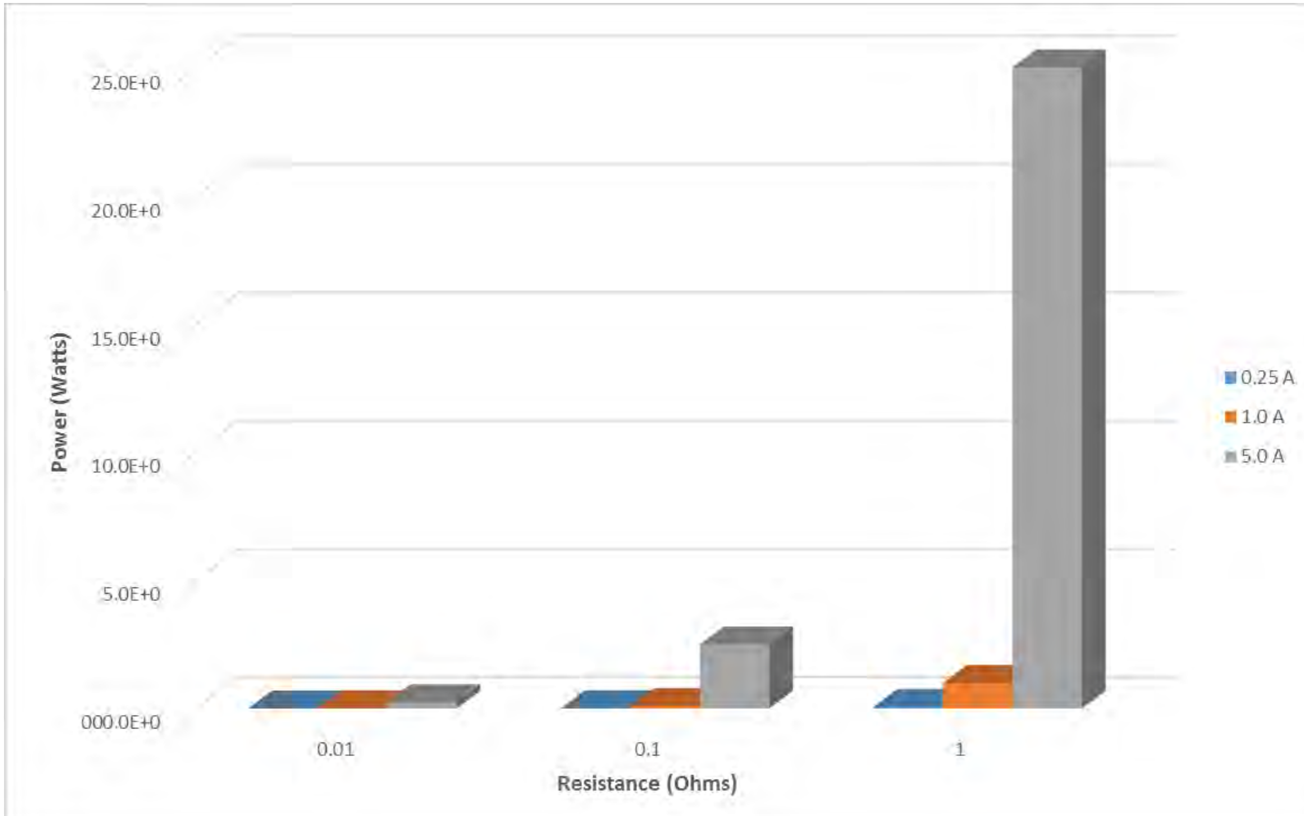
KSPICE Example: C1206C106K8RAC



Why ESR is Important

Power Consumption (Heat)

$$P = I^2 R$$

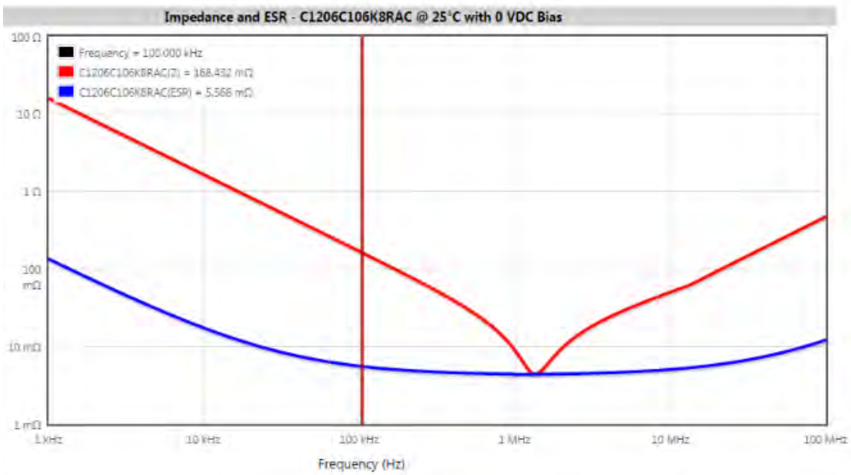


Lower ESR → Lower Power Losses → Higher Efficiency

Ripple Current

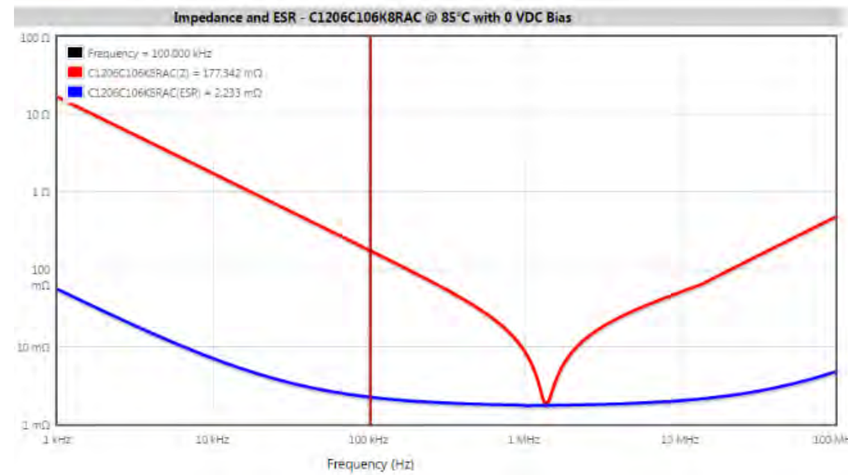
ESR Changes with Temperature

Impedance and ESR - C1206C106K8RAC @ 25°C with 0 VDC Bias



Frequency = 100.000 kHz
C1206C106K8RAC(Z) = 168.432 mΩ
C1206C106K8RAC(ESR) = 5.568 mΩ

Impedance and ESR - C1206C106K8RAC @ 85°C with 0 VDC Bias



Frequency = 100.000 kHz
C1206C106K8RAC(Z) = 177.342 mΩ
C1206C106K8RAC(ESR) = 2.233 mΩ

$$P = I^2 R$$

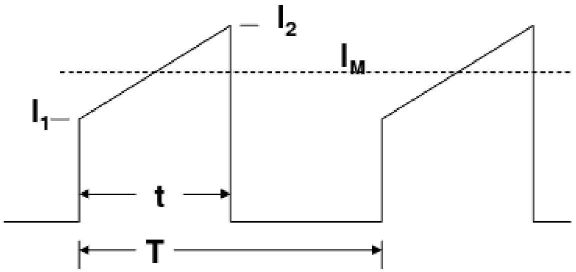
Why ESR is Important

- *Why* ESR is important.
  - Power loss in cap is Irms x Irms x ESR
  - Simplified to Iavg see below (loss a little higher with Irms)

Average Calculation (general trapezoidal waveforms)

$$I_{AVG} = \frac{t}{T} I_M$$

$$I_M = \frac{I_2 + I_1}{2}$$

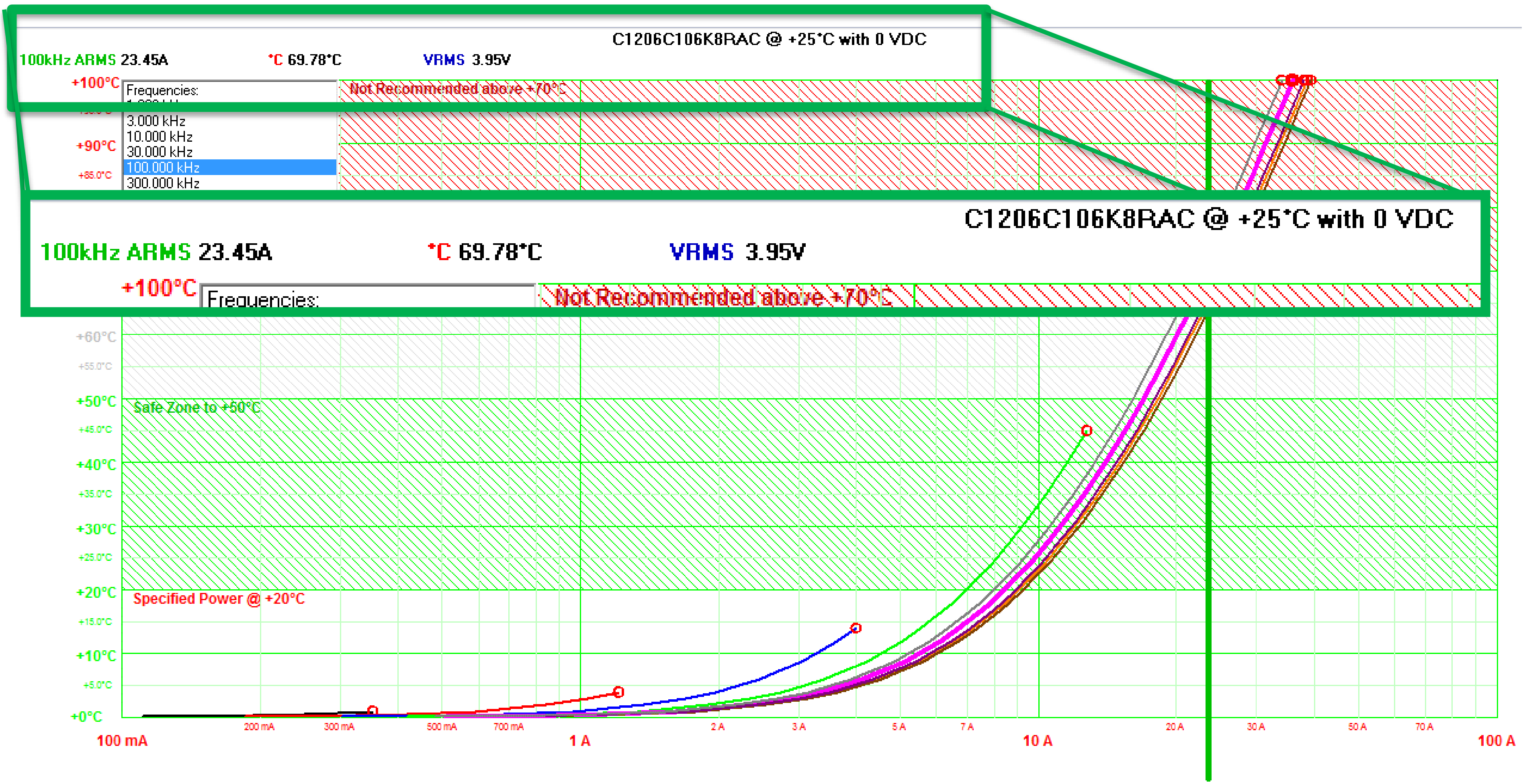


Pavg = 1A x 1A x 0.010ohm = 10mw (using 1A avg current)
Pavg = 5A x 5A x 0.010ohm = 250mw (using 5A avg current)

Lower ESR ➔ Lower Power Losses ➔ Higher Efficiency

Ripple Current

Temperature Rise



Choosing Capacitors for Low Voltage DC

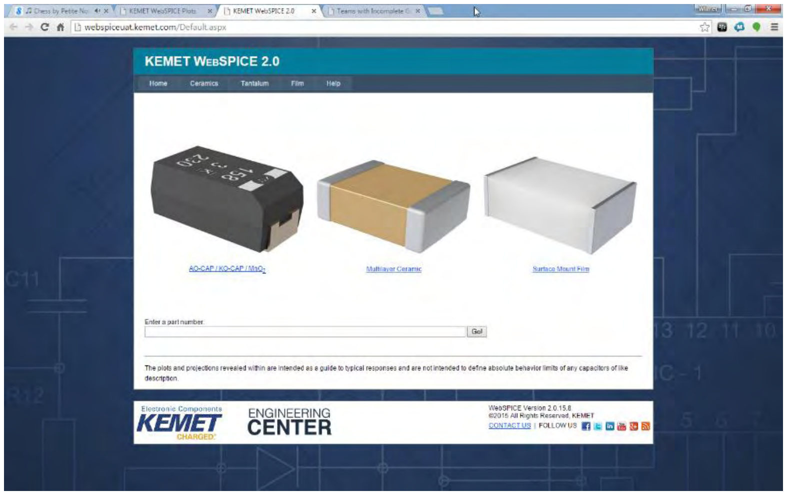
K-Sim (WebSPICE) Usage and Techniques

Common K-Sim Use Cases

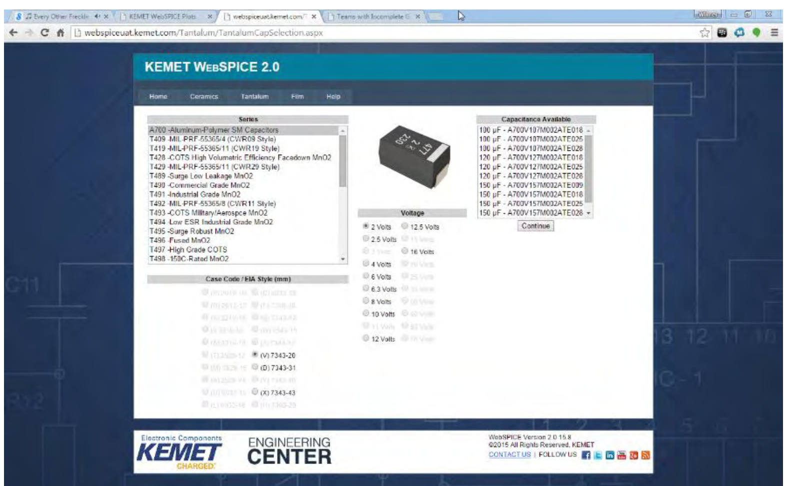
- Finding impedance and ESR
- Finding capacitance and inductance
- Finding the maximum allowable ripple current
- Finding the temperature rise given ripple
- Finding effective capacitance when a bias is applied
- Finding and exporting the equivalent circuit model
- Exporting scattering parameters
- Finding combined impedance of multiple capacitors
- Comparing performance under multiple conditions
- Y-Value tracking and crosshair locking

K-Sim Basics

- K-Sim is located at ksim.kemet.com



The K-Sim homepage is the main starting point where the capacitor type is selected.



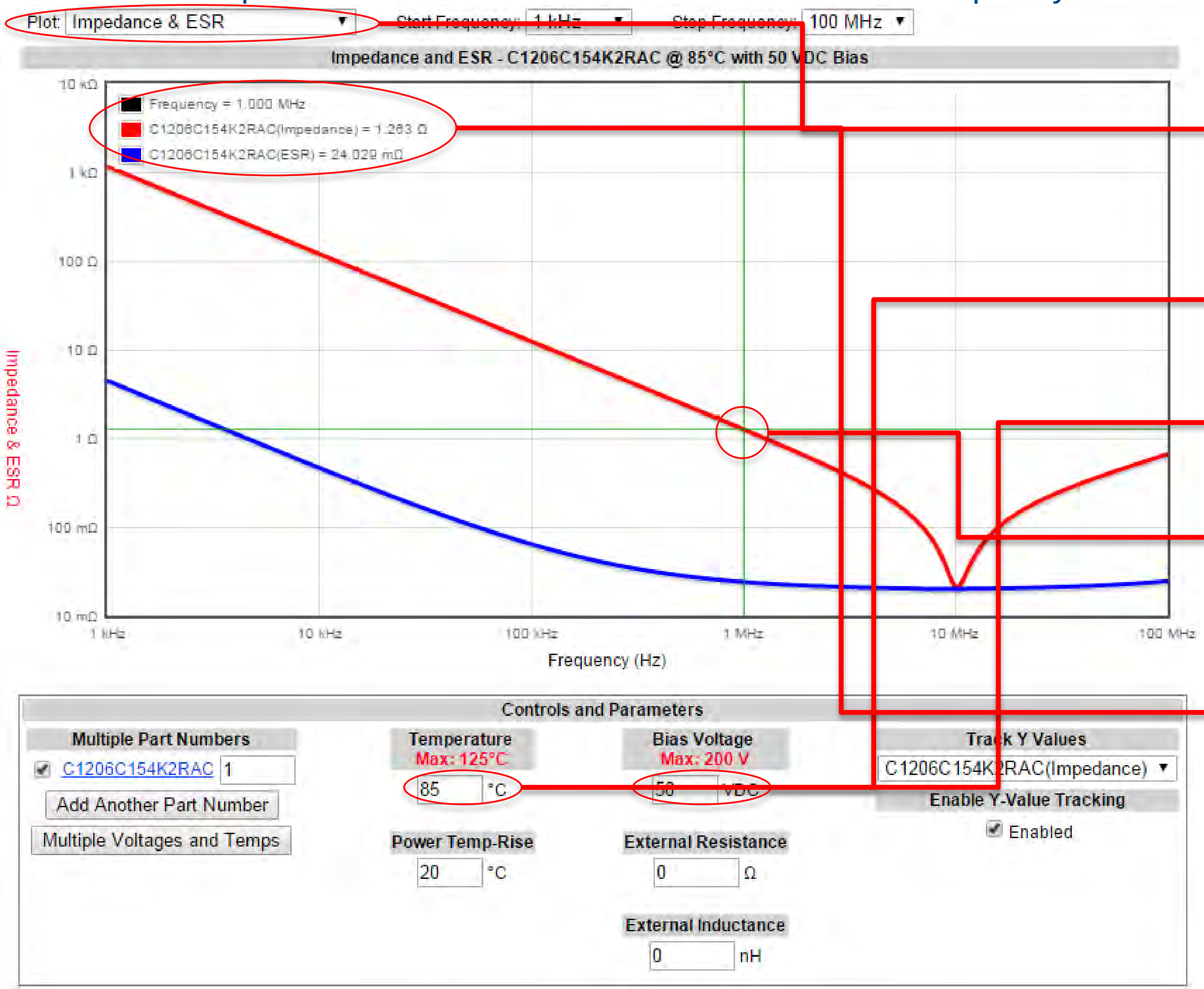
Each part family has a selection screen where the desired specifics for the desired part (i.e. capacitance, rated voltage, size).

Finding Impedance and ESR

- What is the impedance and ESR of C1206C154K2RAC at a frequency of 1MHz with a bias of 50V at 85°C?

Finding Impedance and ESR

- What is the impedance and ESR of C1206C154K2RAC at a frequency of 1MHz with a bias of 50V at 85°C?



Select Impedance and ESR as Plot Type

Set Temperature to 85°C

Set Voltage to 50V

Move Crosshair to 1MHz

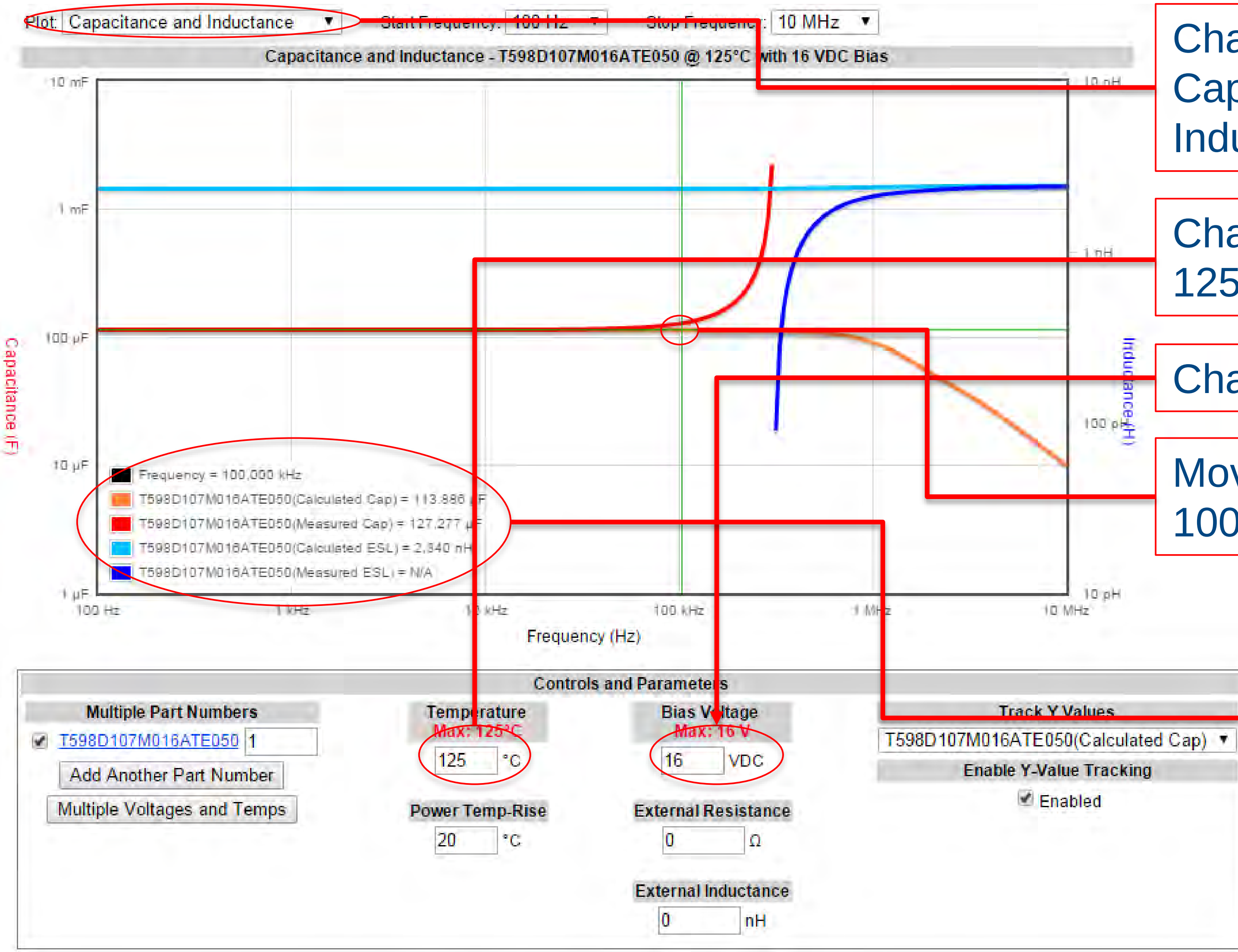
Get Data:
Z=1.263Ω
ESR=24.029mΩ

Finding Capacitance and Inductance

- What is the capacitance and inductance of T598D107M016ATE050 at 125°C with a 16V bias at 100kHz?

Finding Capacitance and Inductance

- What is the capacitance and inductance of T598D107M016ATE050 at 125°C with a 16V bias at 100kHz?



Change Plot to Capacitance and Inductance

Change Temperature to 125°C

Change Voltage to 16V

Move Crosshair to 100kHz

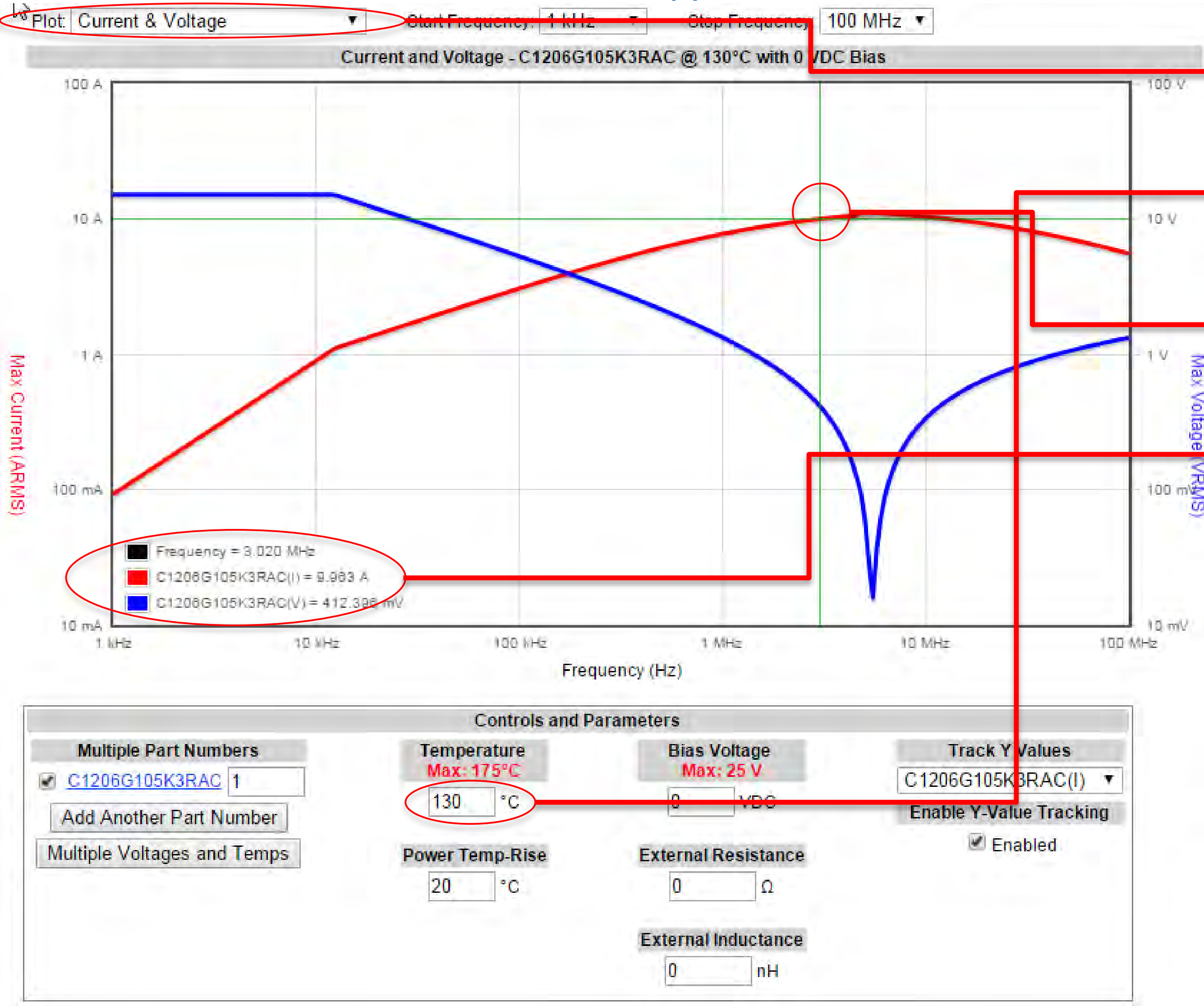
Get Data:
C(calc)=113.88µF
C(meas)=127.27µF
L(calc)=2.34nH
L(meas)=N/A

Finding Maximum Allowable Ripple Current

- What is the maximum allowable ripple current for C1206G105K3RAC at 130°C and 3MHz?

Finding Maximum Allowable Ripple Current

- What is the maximum allowable ripple current for C1206G105K3RAC at 130°C and 3MHz?



Change Plot to Current and Voltage

Set the Temperature

Move Crosshair to 3MHz

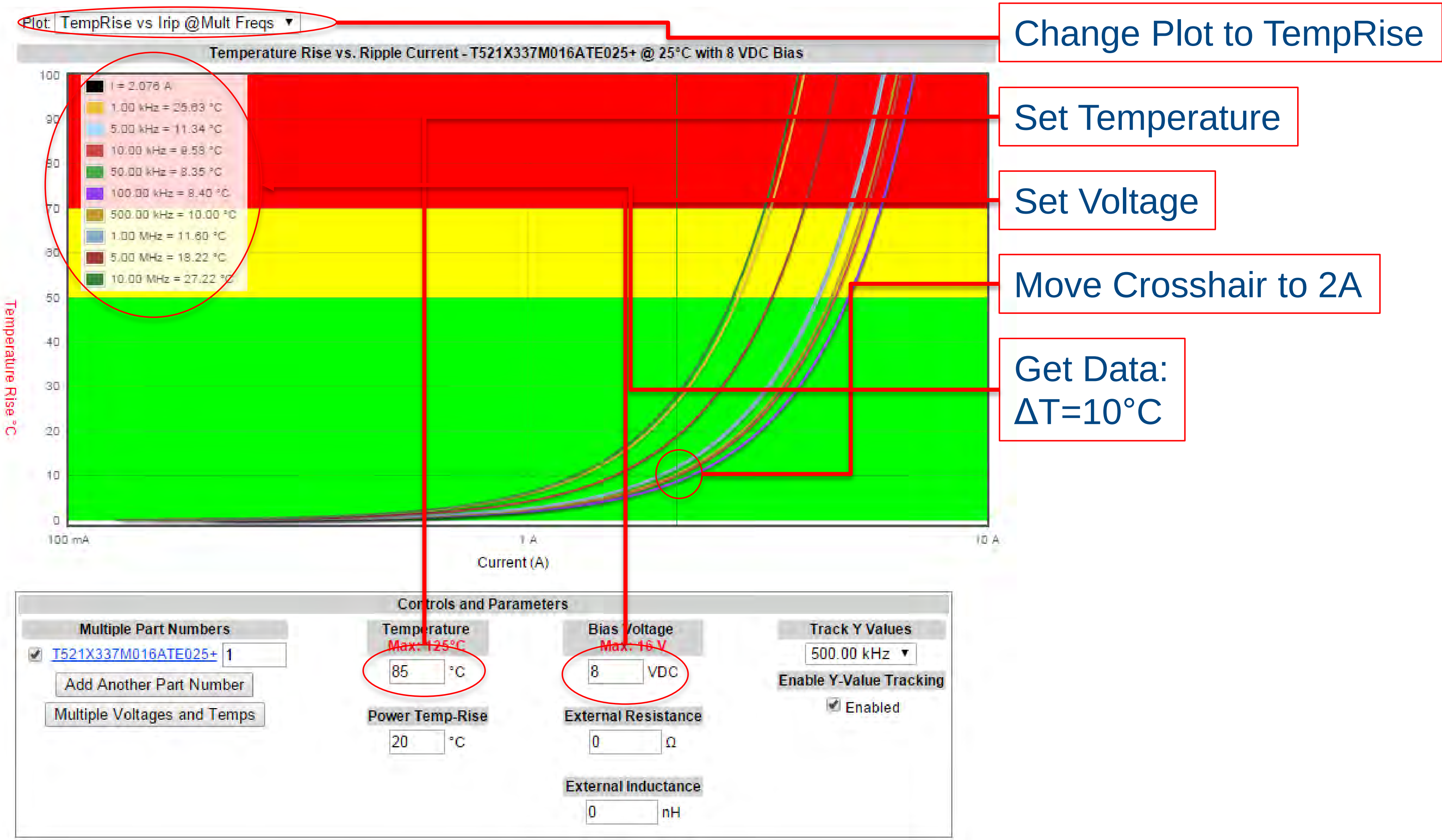
Get Data:
I=9.963A
V=412mV

Finding the Temperature Rise Given Ripple

- How much will the temperature rise on T521X337M016ATE025 at 85°C and 8V bias at 2A and 500kHz?

Finding the Temperature Rise Given Ripple

- How much will the temperature rise on T521X337M016ATE025 at 85°C and 8V bias at 2A and 500kHz??

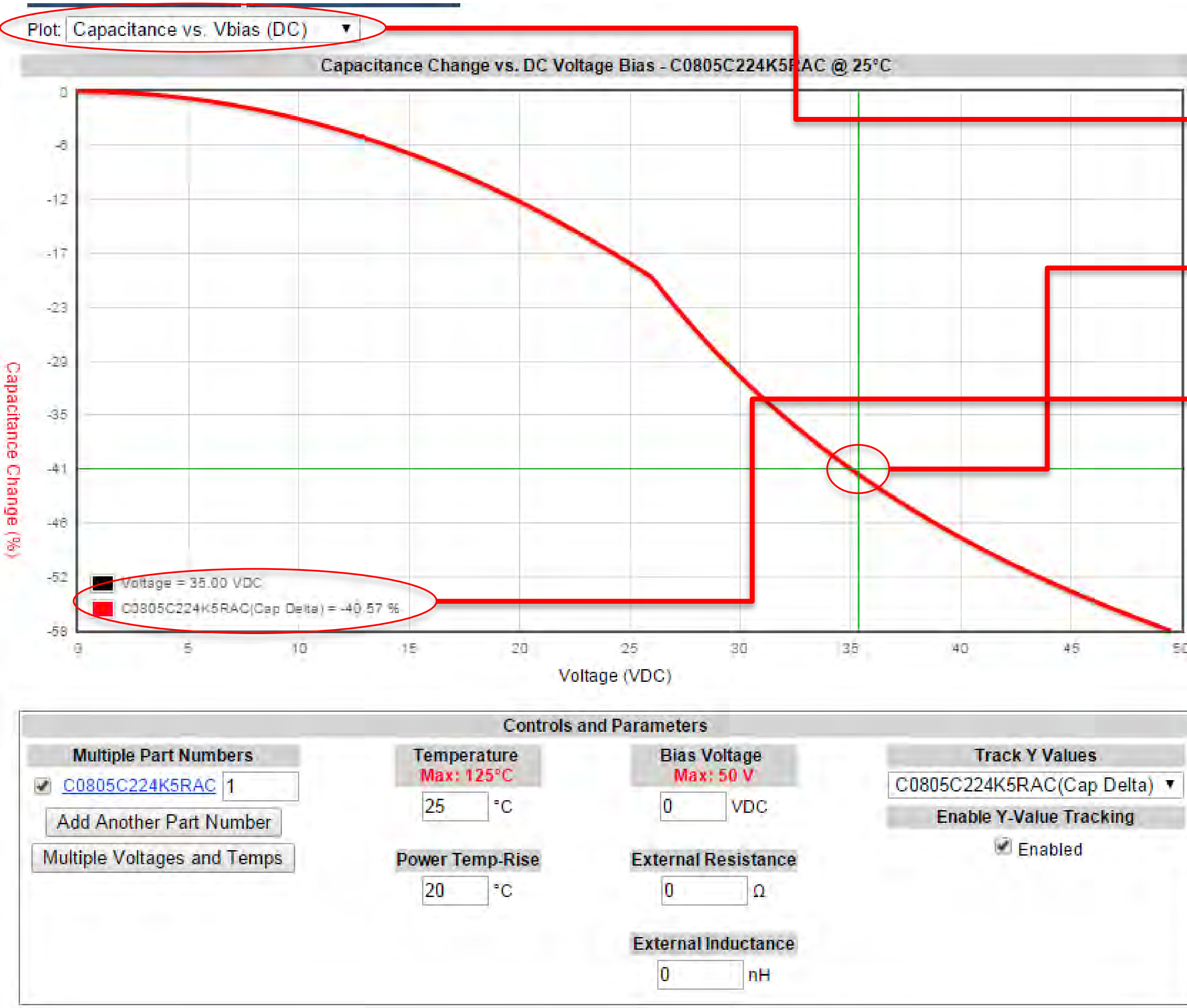


Finding Capacitance With Applied DC Bias

- How much capacitance is available with C0805C224K5RAC when 35V are applied?

Finding Capacitance With Applied DC Bias

- How much capacitance is available with C0805C224K5RAC when 35V are applied?



Change Plot to Capacitance vs. Vbias(DC)

Move Crosshair to 35V

Get Data:
Cap drops by 40.5%

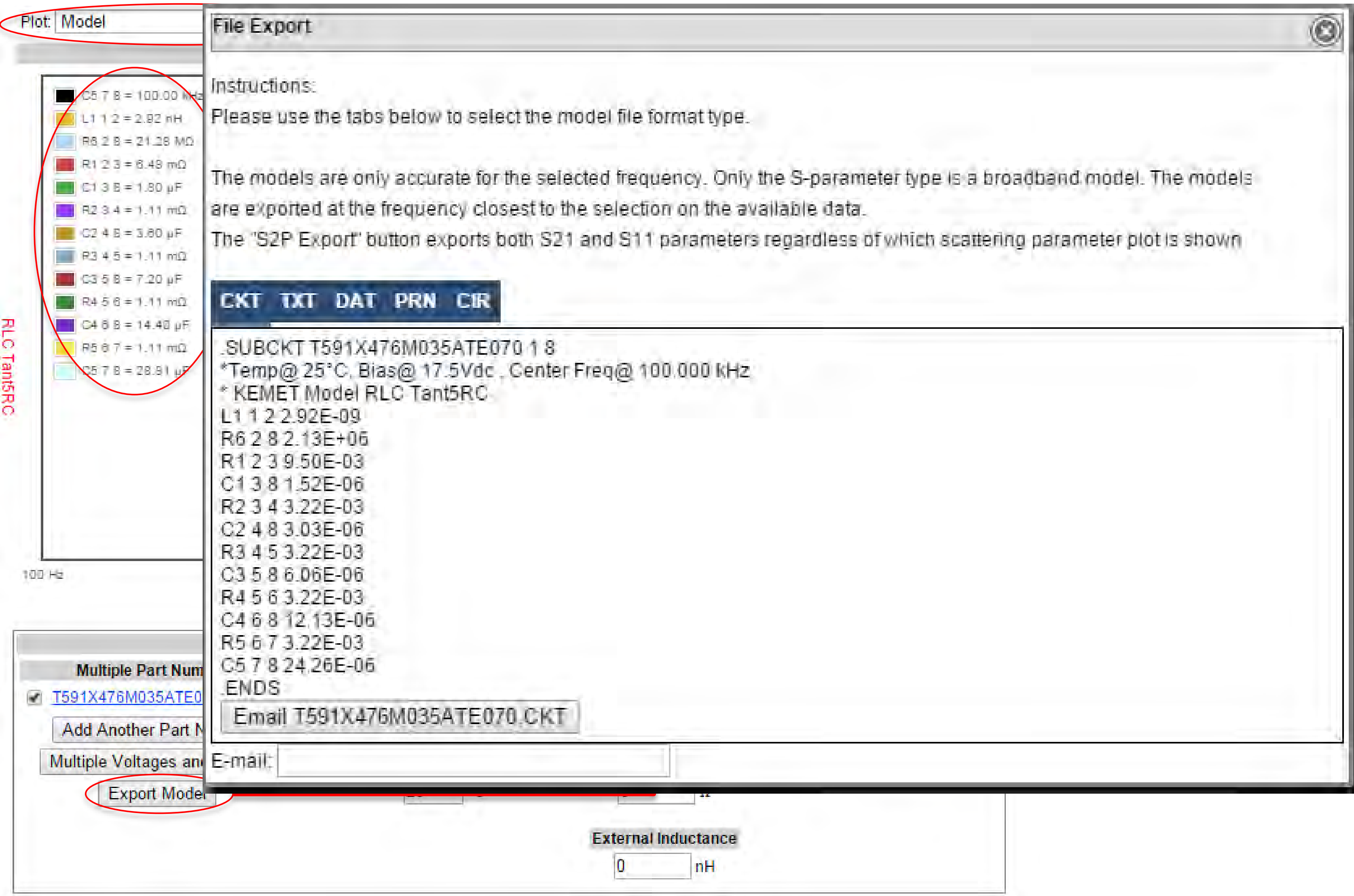
Finding the Equivalent Circuit Model

- What is the lumped circuit element model for T591X476M035ATE070 at 100kHz at 125°C?

Finding the Equivalent Circuit Model

Electronic Components KEMET CHARGED.

- What is the lumped circuit element model for T591X476M035ATE070 at 100kHz at 125°C



Model

e to 125°C

to

etlist

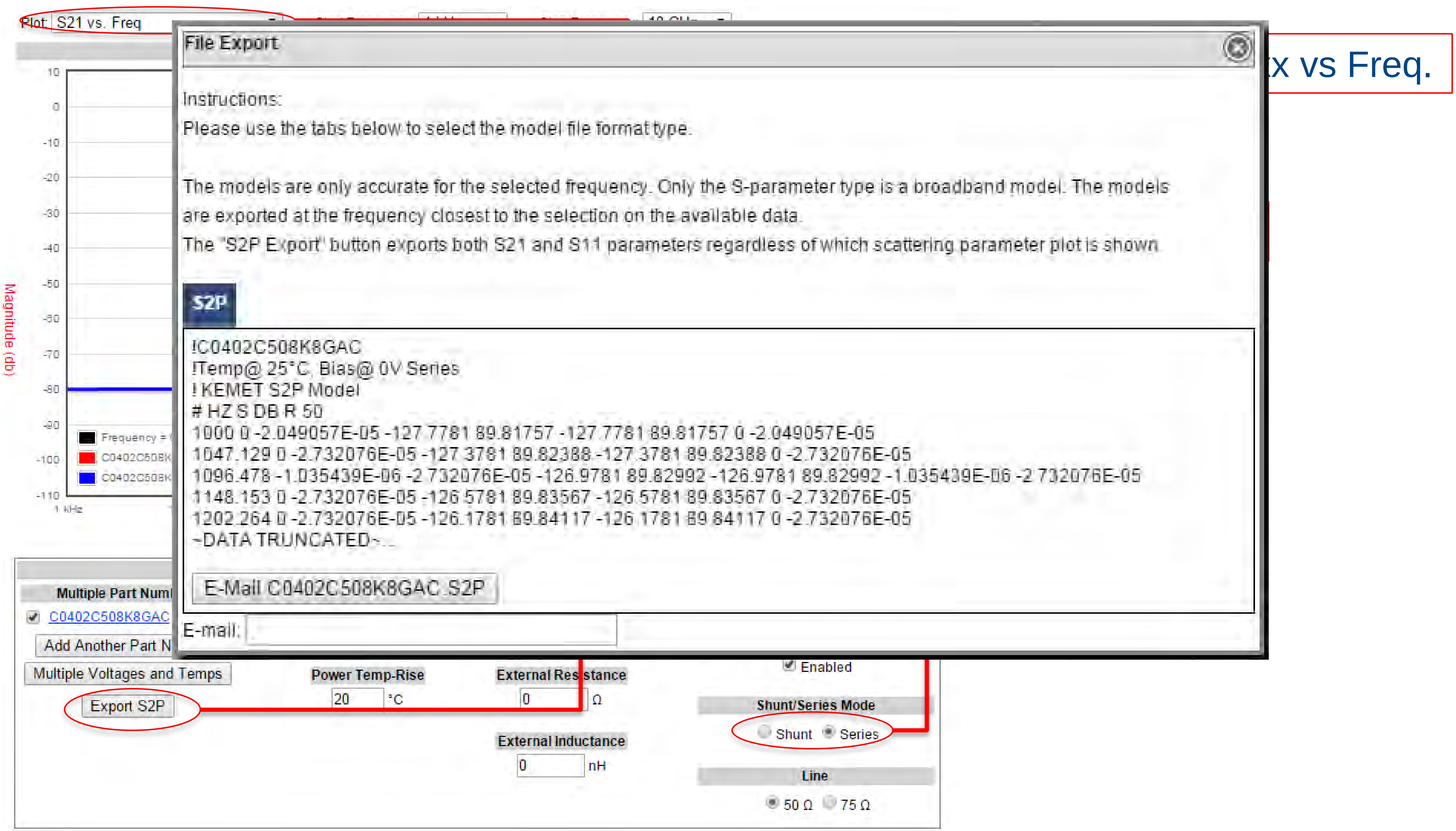
Exporting Scattering Parameters

- How to determine the S-parameters for C0402C508K8GAC at 50Ω in series?

Exporting Scattering Parameters

Electronic Components KEMET CHARGED.

- How to determine the S-parameters for C0402C508K8GAC at 50Ω in series?

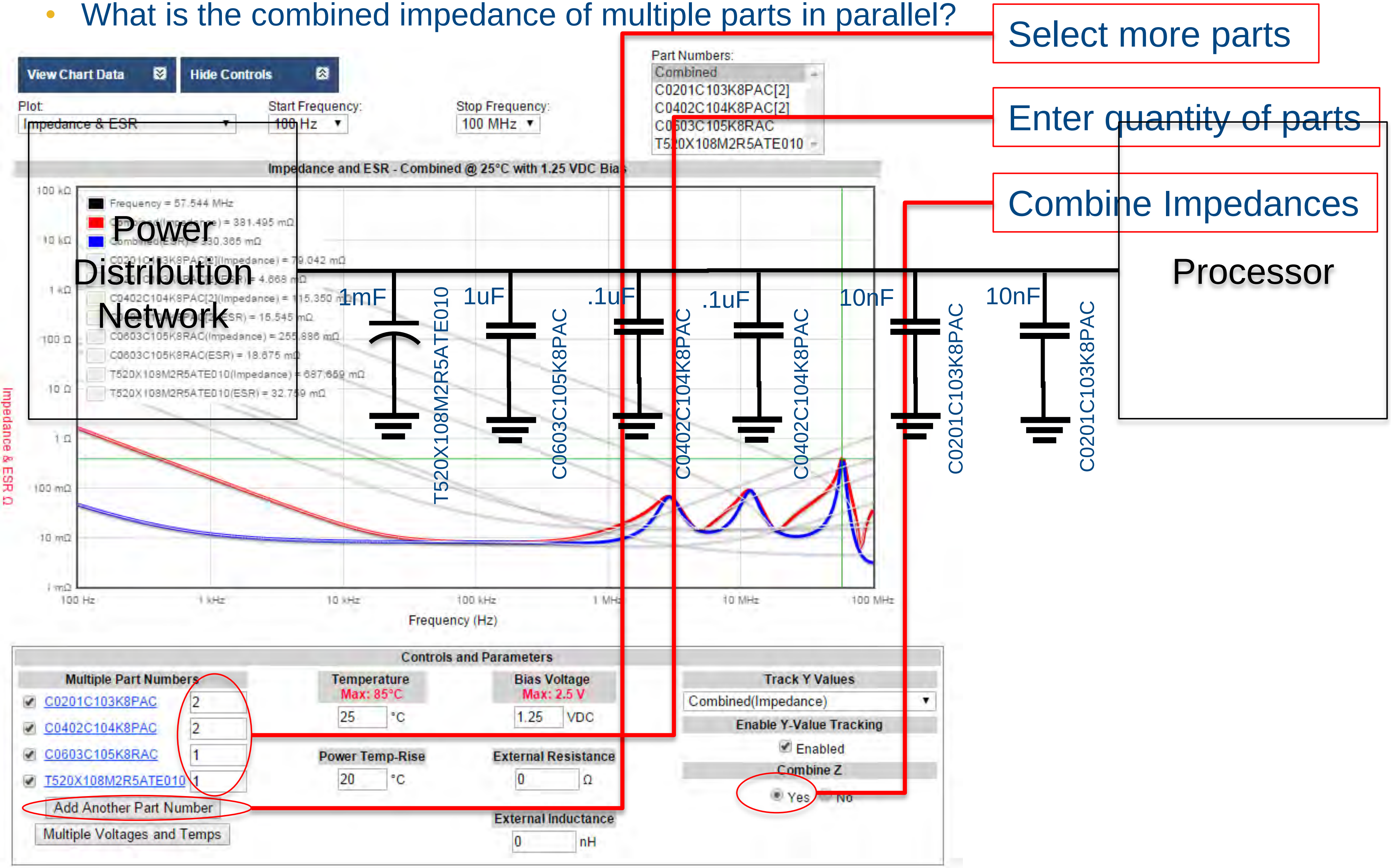


Finding Combined Impedances

- What is the combined impedance of multiple parts in parallel?

Finding Combined Impedances

- What is the combined impedance of multiple parts in parallel?

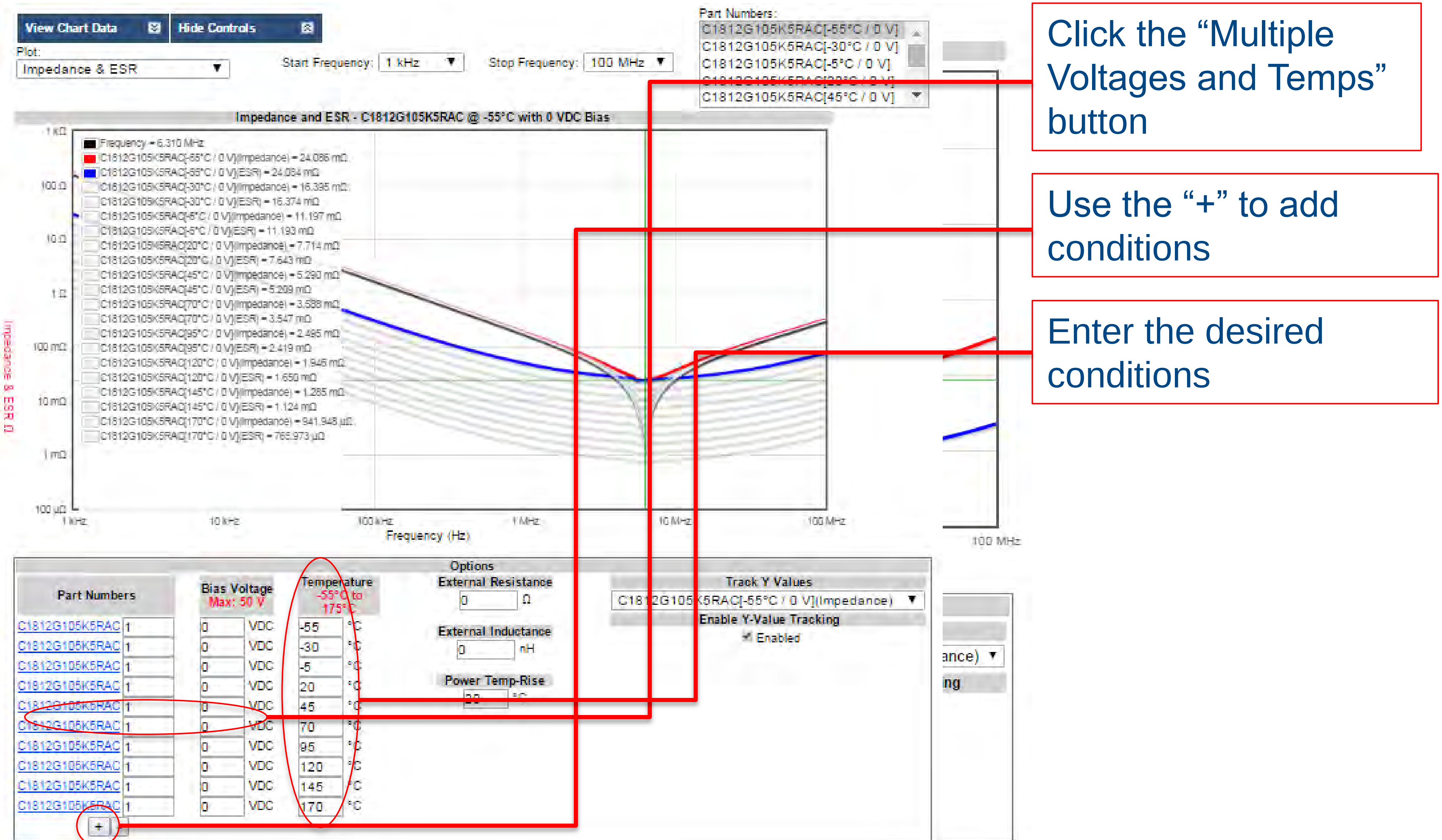


Comparing Performance Under Multiple Conditions

- How do the impedance and ESR of C1812G105K5RAC change over temperature?

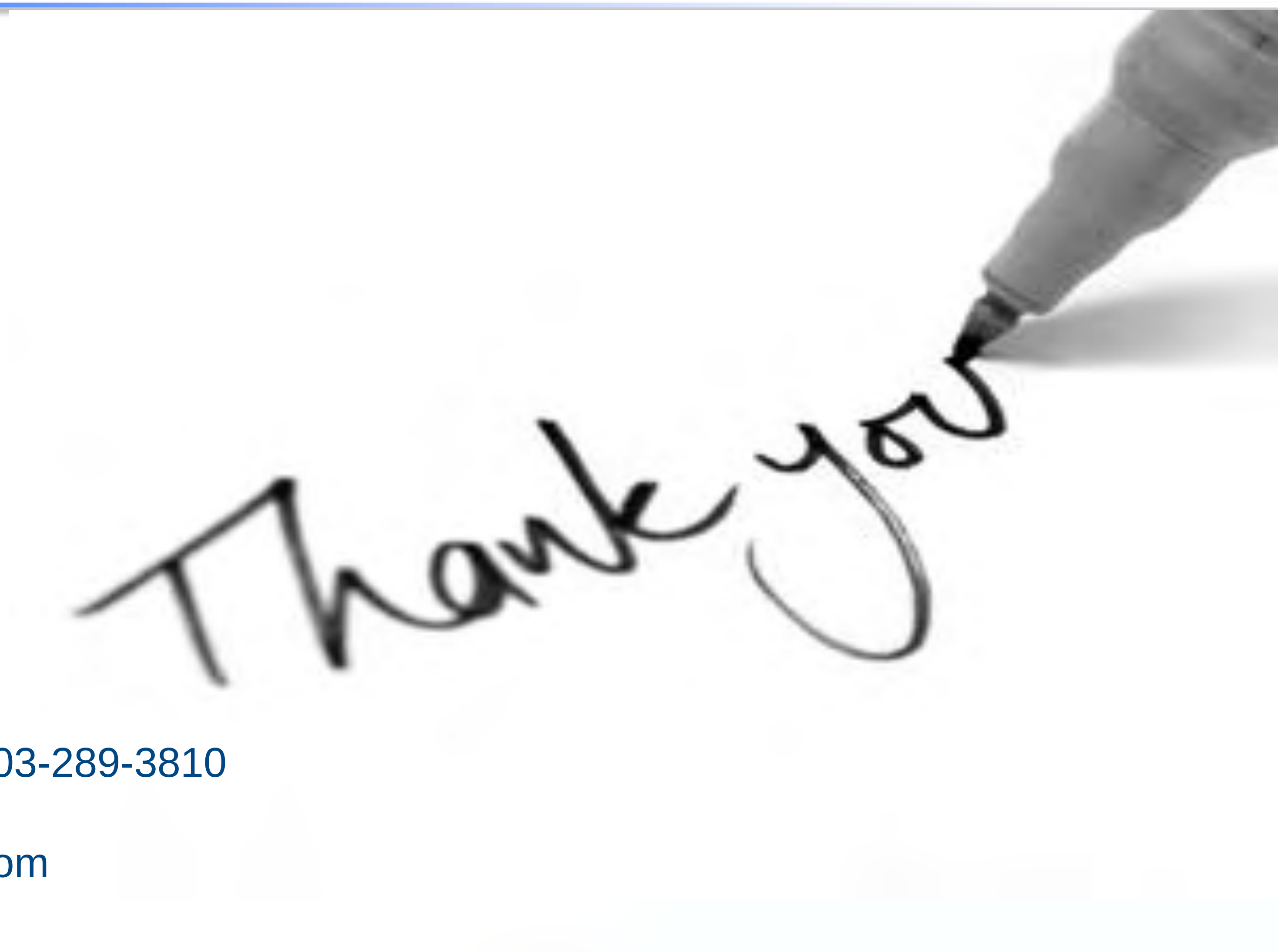
Comparing Performance Under Multiple Conditions

- How do the impedance and ESR of C1812G105K5RAC change over temperature?



Y-Value Tracking and Crosshair Locking

- Use dropdown box to select which Y-Value the crosshairs will track.
- The crosshair will retain their locked position even when changing plots.



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