Systems Engineering

Passive Components

Pere Palà

iTIC http://itic.cat

v1.2 March 2012

Resistors

Resistors

- Ubiquitous
- Uncritical

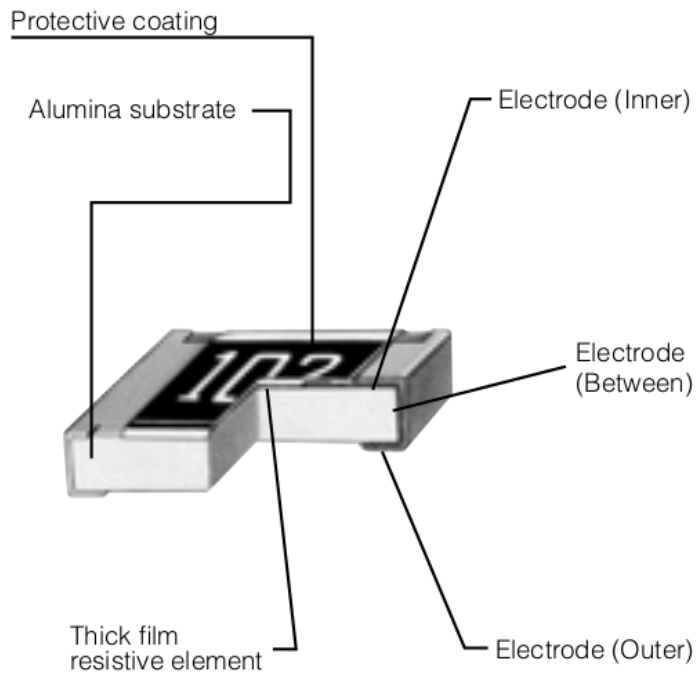
Resistor Types

- Surface mount chip
- Metal film
- Carbon
- Wirewound
- Precision resistors
- Resistor networks

Useful info `http://resistorguide.com`

Surface Mount Chip Resistors

- Standard: Thick film surface mount chip type
- Low price
- Simple construction
- Tolerances ±5 %, ±2 %, ±1 % typical.
- Power dissipation limited: depending on the pads (0805→ 0.125W)
- Higher performance: metal film chip resistor



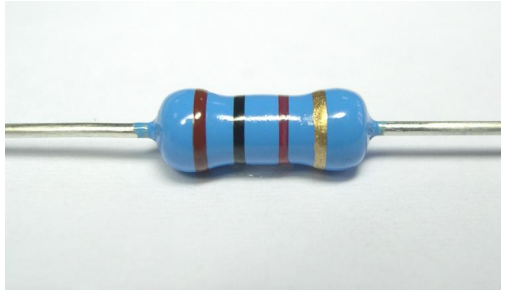
Surface Mount Chip Sizes

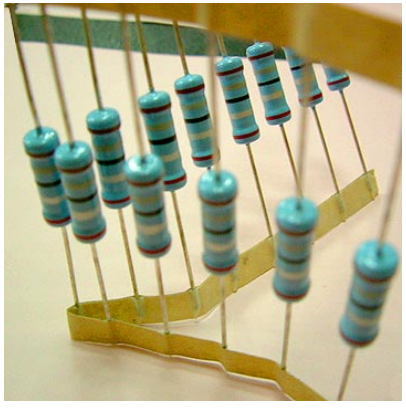
Size	Dimensions mm L x W x H
0201	0.6 x 0.3 x 0.25
0402	1.0 x 0.5 x 0.25
0603	1.6 x 0.8 x 0.45
0805	2.0 x 1.25 x 0.5
1206	3.2 x 1.6 x 0.6
1210	3.2 x 2.6 x 0.6
2010	5.1 x 2.5 x 0.6
2512	6.5 x 3.2 x 0.6

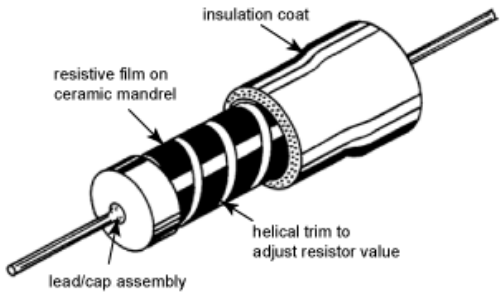
Metal Film Resistor

Features

- Leaded devices
- Laser-cut helical path
- Standard part in through-hole technology
- Somewhat inductive
- Tolerances ± 2 %, ± 1 % typical
- Temperature coefficient 25—50 ppm/°C



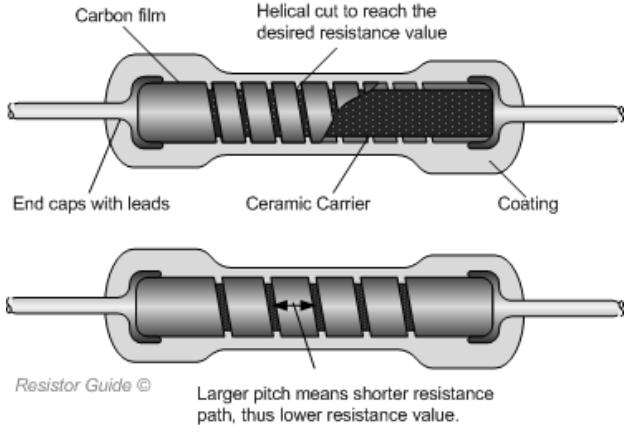




Carbon Film Resistors

Features

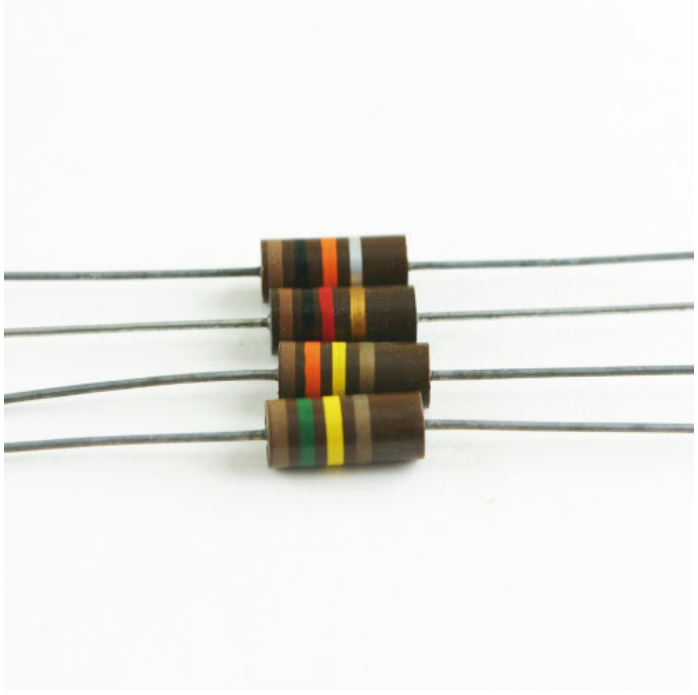
- Cheap
- Better than carbon composition
- Inductive
- Tolerances ± 20 %, ± 10 %, ± 5 % typical.
- Carbon film, carbon composition
- Pulse withstand capability

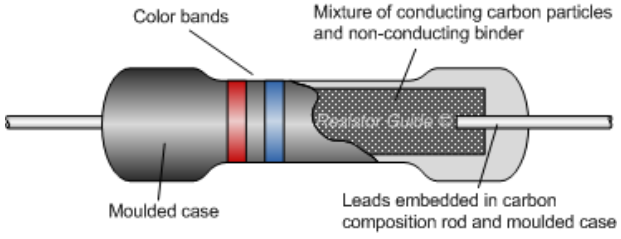


Carbon Composition Resistors

Features

- Cheap
- Limited performance
- Noisier
- Higher resistance than wirewound
- Poor tolerance
- High temperature coefficient
  1200 ppm/°C
- Pulse withstand capability.
  Applications: protection, current limiting...

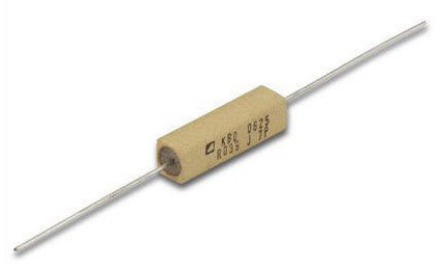




Wirewound Resistors

Features

- Oldest technology
- Precision or High-power
- Core material: ceramic, plastic, glass
- May be very accurate
- Very inductive
- May exhibit tight tolerances: 0.1% or better
- Low temperature coefficient 5 ppm/°C
- Power 1 W to 1000 W
- Temperature up to 300 °C



Precision Resistors

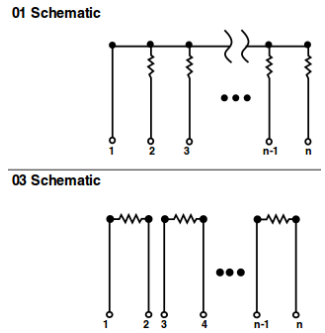
Foil Resistor

- 10 kΩ
- Tolerance ±0.005 %
- Temperature coefficient ±0.05 ppm/°C
- 25 €

Resistor Networks

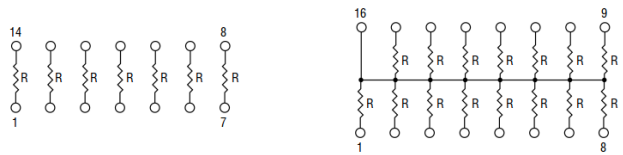
Production Efficiency

- Handling and insertion cost
- Several resistors of one value
- Dual-in-line Single-in-line
- Production vs Board layout (long tracks) ⚠



Value Tracking (ppm/ °C)

- Tolerance similar to single resistors
- Tracking with temperature is better
- 250 individual but 50 tracking
- Thin film 25 / 5



Survey of resistor types

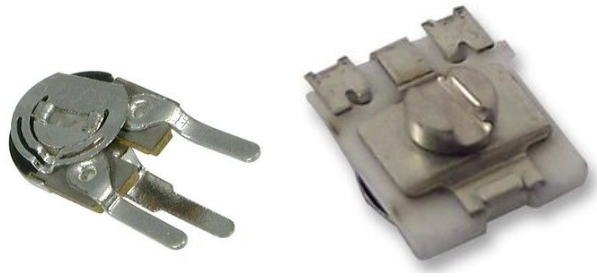
Type	Ohmic Range	Power W	Tolerance	Tempco range ppm/°C	Applications	Cost
Carbon film	2.2 - 10M	0.25 - 2	5%	150 – -1000	General purpose commercial	$<$ 1p
Carbon composition	2.2 - 10M	0.25 - 1.0	10%	+400 – -900	Pulse, low inductance	
Metal film (standard)	1 - 10M	0.125 - 2.5	1%, 2%, 5%	+/-50 – 200	General purpose industrial & military	1 - 3p
Metal film (high ohm)	1M - 100M	0.5 - 1	5%	+/-200 – 300	High voltage & special	5 - 20p
Metal glaze	1 - 100M	0.25	2%, 5%	+/-100 – 300	Small size	5p
Wirewound	0.1 -33K	2 - 20	5%, 10%	+/-75 – 400	High Power	15 - 50p
Metal film (precision)	5 - 1M	0.125 - 0.4	0.05 – 1%	+/-15 – 50	Precision	10p - 50p
Wirewound (precision)	1 - 1M	0.1 - 0.5	0.01 – 0.1%	+/-3 – 10	Extra-precision	£2 - £20
Bulk metal (precision)	1 - 200K	0.33 - 1	0.005 – 1%	+/-1 – 5	Extra-precision	10 - 35p
Resistor networks	10 - 1M	0.125 - 0.3 per element	2%	+/-100 – 300 +/-50 tracking	Multi-resistor	0.2p - 2p
SM chip film resistors	0 - 10M	0.1 - 0.5	1%, 2%, 5%	+/-100 – 200	Surface mount, hybrids	

from *The Circuit Designer's Companion* by Tim Williams

Potentiometers

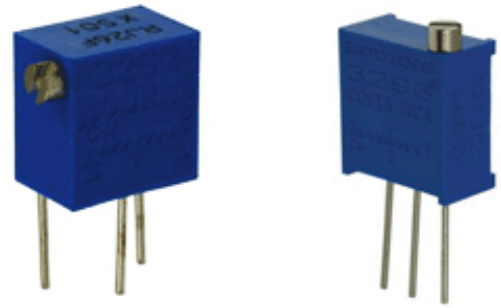
Potentiometers

- Bulky, unreliable
- Usable up to $f \times R < 1 \times 10^6$ Hz-Ω
- Cost time and money
- Substitutable by microcontrollers



Trimmer types

- Carbon, cermet and wirewound
- Multi-turn



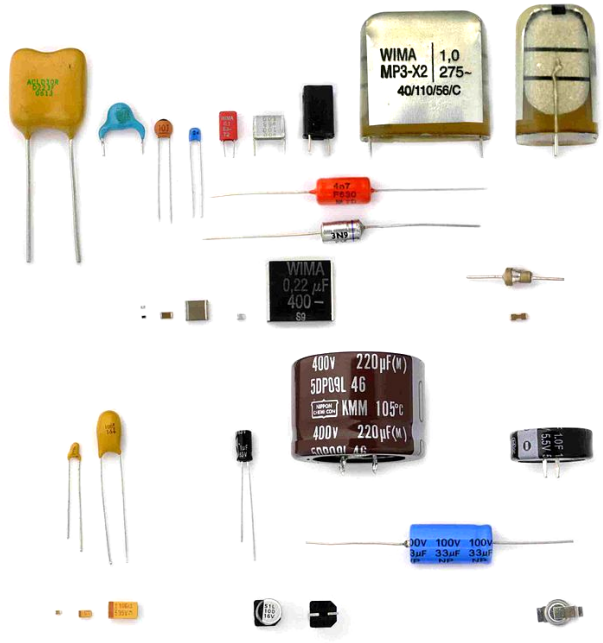
Panel types

- Carbon, cermet and wirewound
- Conductive plastic

Capacitors

Types

- Film
  - Polyester, Polycarbonate, Polypropylene, Polystyrene
- Paper
- Ceramic
  - Single layer
    - Barrier layer, high-K, low-K
  - Multilayer
    - C0G, X5R, X7R, Z5U
- Electrolytic
  - Non-solid and solid aluminium, solid tantalum



Capacitor Selection

Technology

- Aluminum (96)
- Ceramic (155)
- Film (76)
- Power - Heavy Current (ESTA) (21)
- Tantalum (89)
- Thin Film (4)

Mounting and Construction

- Surface Mount (82)
  - Molded (27)
  - Conformal Coated (16)
  - Face-Down (4)
  - Low Profile (7)
- Leaded/Through-hole (238)
  - Radial (118)
  - Axial (68)
  - Snap In/Screw Terminal (41)
  - Button (5)
  - Solder Lug (2)
- Assemblies and Arrays (4)
- Wire Bondable (3)

Special Characteristics

- Board-flex Sensitive (2)
- Double Layer (1)
- General Purpose (36)
- High Reliability/Long-life (62)
- High Temperature (22)
- High Frequency (15)
- Low ESR (34)
- Pulse Capacitor (16)

Applications

- Automotive (22)
- Computer (27)
- Consumer (56)
- Industrial (144)
- Medical (32)
- Military/Aerospace (110)
  - QPL/MIL (31)
  - CECC/EN (8)
  - DSCC (15)
  - High Reliability (62)
- Power - Heavy Current (ESTA) (21)
- RF / Wireless Handheld (16)
- Telecommunications (52)
  - Infrastructure (37)
  - Mobile Devices (44)

Capacitance

- below 1 nF (141)
- 1 nF to 100 nF (118)
- 101 nF to 10 µF (102)
- 10.1 µF to 1 mF (147)
- above 1 mF (108)

Voltages

- below 10 V (136)
- 10 V to 25 V (183)
- 26 V to 50 V (172)
- 51 V to 100 V (146)
- 101 V to 500 V (190)
- 501 V to 2000 V (70)
- above 2000 V (65)

Output

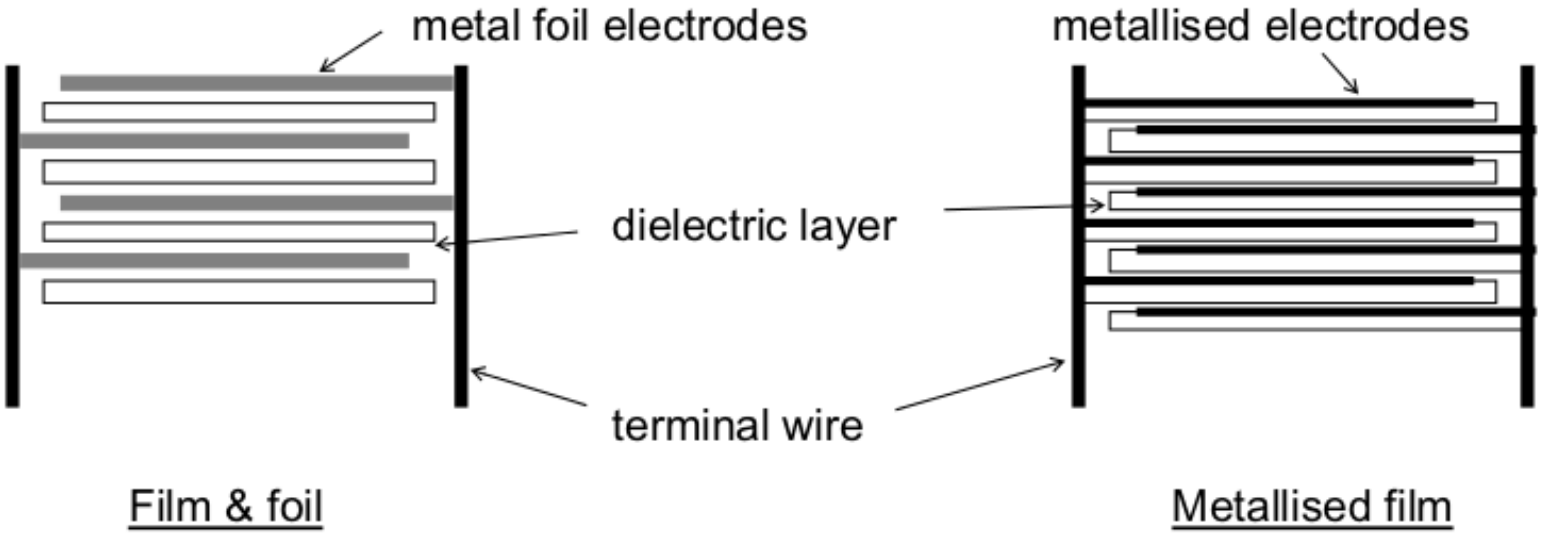
- up to 100 kvar (1)
- above 100 kvar (6)

`http://www.vishay.com/capacitors/`

Metalized film & paper

Construction

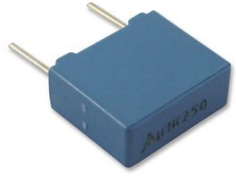
- Film & Foil: Thicker construction
- Metalized Foil: Thinner, higher capacitance



Film Capacitors

Polyester

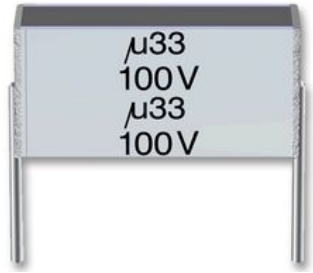
- High dielectric constant. High capacitance per unit volume
- Applications: Decoupling, bypassing
- Nonlinear
- High dissipation factor $\delta = 8 \times 10^{-3}$ @1 kHz, 20°, variable with temperature
- Suitable only for uncritical circuits



Film Capacitors

Polycarbonate

- Flat temperature-capacitance curve
- Lower dissipation factor $\delta < 2 \times 10^{-3}$ @1 kHz, 20°
- Suitable for filters and timing functions
- Good general-purpose dielectric for higher power use



Film Capacitors

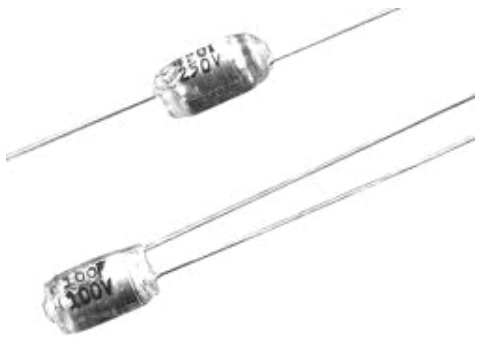
Polypropylene

- Lower dielectric constant. Does not metalize as easily. Larger devices for a given CV product.
- Constant tempco -200 ppm/°. Unsuitable for time or frequency critical circuits. Constant tempco usable for compensation
- Low dissipation factor $\delta = 3 \times 10^{-4}$ @1 kHz, 20°, constant with T. Higher power at higher frequencies.
- Tight tolerances
- Usable for sample-and-hold circuits due to good dielectric absortion

Film Capacitors

Polystyrene

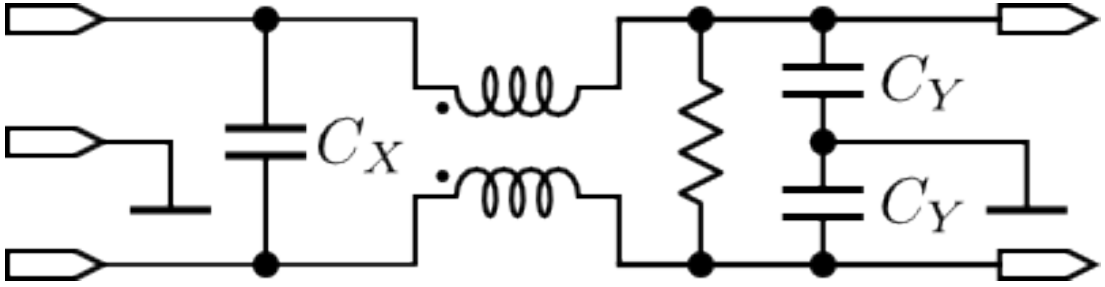
- Similar to polypropylene capacitors
- Low dielectric loss, low dielectric absorption
- Good stability over time
- Low negative temperature coefficient



Film Capacitors

Metalized paper

- Historically wide-used
- Absorbs moisture
- Current use: mains interference suppressor
  - Fault in dielectric $\rightarrow$ fire
  - Paper regenerates under faults
  - Marking X/Y/Z. X:Low T, Y:High T, Z:# of days in damp heat test
  - $C_X = 100$ nF, $C_Y = 4.7$ nF, $L = 22$ mH, $R = 1$ MΩ
  - X Failure $\rightarrow$ fire. Y failure $\rightarrow$ user shock



X and Y capacitors

2.1 X capacitors

These are capacitors for applications in which failure of the capacitor will not lead to a dangerous electrical shock. EN 60384-14 divides X capacitors into 3 sub-classes according to the peak pulse voltage to which they are exposed in operation, in addition to the rated voltage. This kind of impulse can be caused by lightning in overhead cables, switching surges in neighbouring equipment or in the device in which the capacitor is used to suppress interferences.

Sub-class	Peak pulse voltage V_p in operation	Application	Peak values of surge voltage V_p (before endurance test)	
X1	$2.5\ \text{kV} < V_p \leq 4.0\ \text{kV}$	High pulse application	$C_R \leq 1.0\ \mu\text{F}$:	$V_p = 4.0\ \text{kV}$
			$C_R > 1.0\ \mu\text{F}$: (enter C_R in µF)	$V_p = \frac{4}{\sqrt{C_R}}\ \text{kV}$
X2	$V_p \leq 2.5\ \text{kV}$	General purpose	$C_R \leq 1.0\ \mu\text{F}$:	$V_p = 2.5\ \text{kV}$
			$C_R > 1.0\ \mu\text{F}$: (enter C_R in µF)	$V_p = \frac{2.5}{\sqrt{C_R}}\ \text{kV}$
X3	$V_p \leq 1.2\ \text{kV}$	General purpose	No test	

Note: Sub-class X3 corresponds to sub-class X2 as described in EC 60384-14 (1st edition).

Source: EPCOS EMI suppression capacitors

X and Y capacitors

2.2 Y capacitors

These capacitors are intended for use where failure of the capacitor could result in a dangerous electrical shock. Y capacitors are capacitors of enhanced electrical and mechanical reliability and limited capacitance. The enhanced electrical and mechanical reliability are intended to eliminate short-circuits in the capacitor. Limitation of the capacitance is intended to reduce the current passing through the capacitor when AC voltage is applied and to reduce the energy content of the capacitor to a limit that is not dangerous when DC voltage is applied.

Y capacitors are used in electrical equipment and machines to bridge operational insulation that provides safety, in connection with additional protective measures, in order to avert danger to humans and animals.

EN 60384-14 divides Y capacitors into the following sub-classes:

Sub-class	Type of bridged insulation	Rated AC voltage	Peak values of surge voltage V_p (before endurance test)
Y1	Double or reinforced insulation	$V_R \leq 250$ V	8.0 kV
Y2	Basic or supplementary insulation	$150\ V \leq V_R \leq 250$ V	5.0 kV
Y3	Basic or supplementary insulation	$150\ V \leq V_R \leq 250$ V	No test
Y4	Basic or supplementary insulation	$V_R < 150$ V	2.5 kV

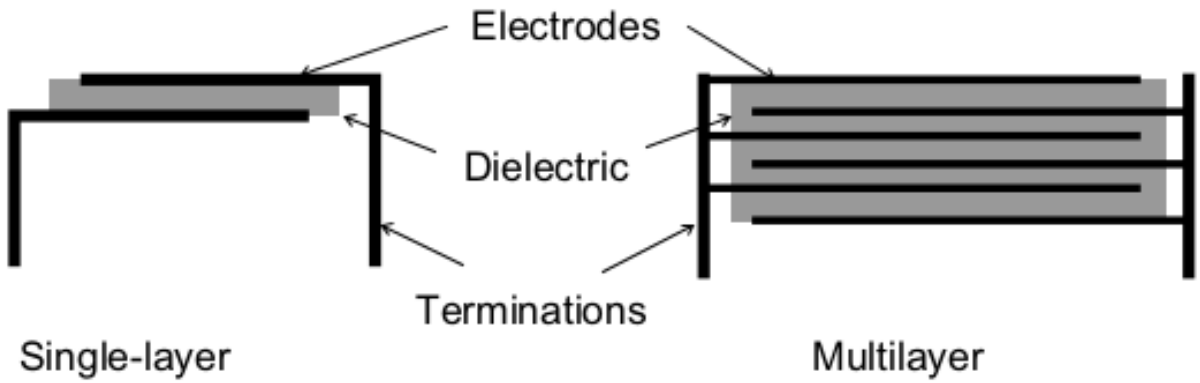
Note: Sub-class Y3 corresponds to class Y as described in IEC 60384-14 (1st edition).

Source: EPCOS EMI suppression capacitors

Ceramic capacitors

Construction

- Fired ceramic / electrode construction: monolithic
- Chip or lead form

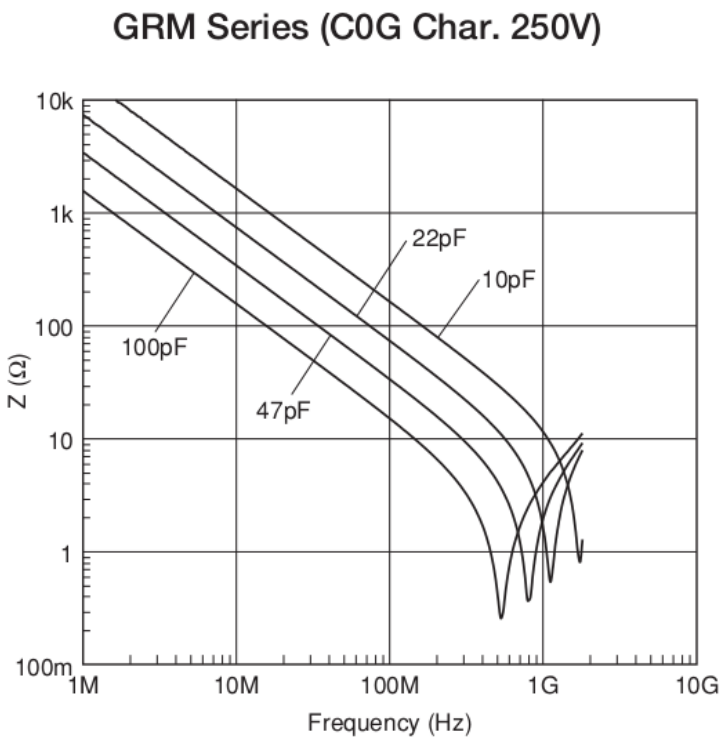


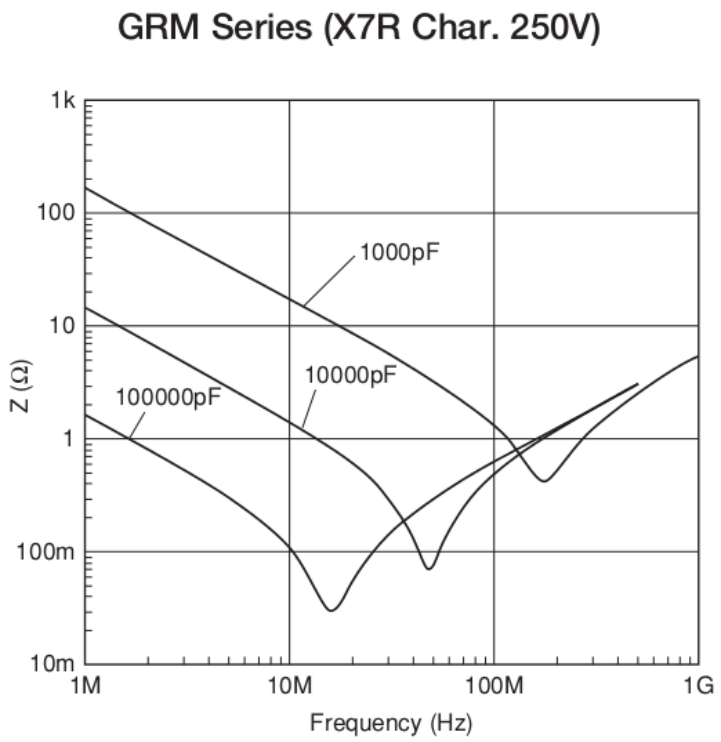
Multilayer ceramic

Dielectrics

- COG (NP0) Low permittivity: low capacitance. Near zero tempco (NP0) dissipation factor $\delta = 1 \times 10^{-3}$ @1 kHz, 20°. High-stability applications $\leftrightarrow$ polycarbonate.
- X5R, X7R. Capacitance up to $\sim 10\mu$ F. Nonlinear capacitance and $\tan\delta$. $\tan\delta \sim 0.025$. 0805: 47μ F, 6.3 V Used for coupling and decoupling
- Y5V, Z5U. Capacitance changes by 50% over temperature and voltage. Tolerance -20 %, $+80$ %. High capacitance

Multilayer ceramics frequency response





Electrolytic capacitors

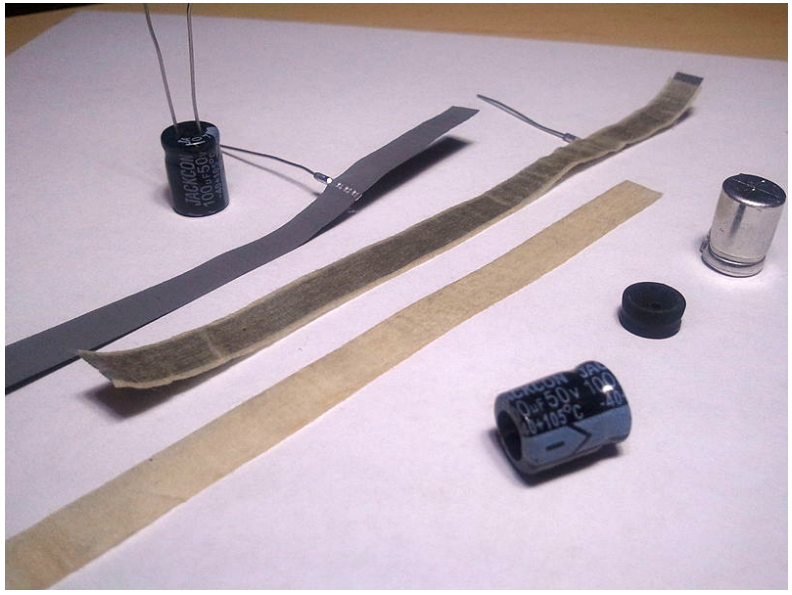
Generics

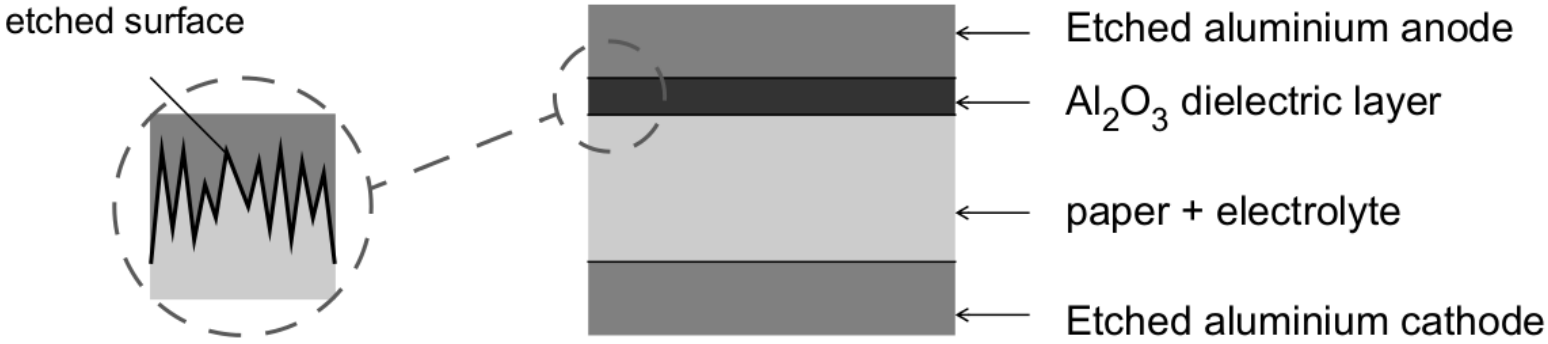
- High capacitance per volume unit
- Solid / non-solid electrolyte
- Typical non-solid aluminium electrolytic: from 1 μF to 470 000 μF
- Polarized. Base metal (anode)
- Ionic conductor. Voltage reversal
- Big and heavy. Mechanical considerations

Electrolytic capacitors

Construction

- Two aluminium foils. One etched and oxidized.
- Paper soaked in electrolyte





Leakage

Leakage

- Typical 0.01 CV, downto 0.002 CV
- Limits performance in some circuits
- Drops to 1/10 with 40% of rated voltage
- Temperature dependent

Ripple current and ESR

- The ac current flowing through capacitor as it charges and discharges, typically at 100 or 120 Hz in power supplies
- I_R rating
- Current dissipates power at the ESR: Equivalent Series Resistance
- Temperature (worse with lower T) and frequency dependent
- ESR is the most important parameter in switching power supplies

Temperature and lifetime

Temperature

- Capacitance reduces with lower T and changes nonlinearly ± 10 %
- $\tan \delta \sim 0.1 - 0.3$ at 20°, worsening with lower T and higher f
- Operational range T: $-40 \cdots +85$ °to 105 °or 125 °

Lifetime

- Non-solid electrolytics degrade when not in use
- Oxide degrades given increased leakage
- May be *reformed* applying voltage through resistor
- Also happens if no dc component is present
- Products stored: high leakage current during first minutes of re-use

Datasheet comparison

- Comparison of datasheets: Panasonic, 25V 100u

Panasonic Aluminum Electrolytic Capacitors/ M

■ Standard Products

W.V. (V)	Cap. (±20 %) (μF)	Case size Dia. (mm)	Case size Length (mm)	Specification Ripple Current (120 Hz) (+85 °C) (mA r.m.s.)	Specification tan δ (120 Hz) (+20 °C)	Lead Length Lead Dia. (mm)	Lead Length Lead Space Straight (mm)	Lead Length Lead Space Taping *B (mm)	Lead Length Lead Space Taping *i (mm)	Part No.	Min. Packaging Q'ty Straight Leads (pcs)	Min. Packaging Q'ty Taping (pcs)
25	100	6.3	11.2	180	0.16	0.5	2.5	5.0	2.5	ECA1EM101( )	200	2000
	330	8	11.5	390	0.16	0.6	3.5	5.0		ECA1EM331( )	200	1000
	470	10	12.5	480	0.16	0.6	5.0	5.0		ECA1EM471( )	200	500
	1000	10	20	850	0.16	0.6	5.0	5.0		ECA1EM102( )	200	500
	2200	12.5	25	1200	0.18	0.6	5.0	5.0		ECA1EM222( )	200	500
	3300	16	25	1300	0.20	0.8	7.5	7.5		ECA1EM332( )	100	250
	4700	16	31.5	1500	0.22	0.8	7.5			ECA1EM472	100	
	6800	18	35.5	1750	0.26	0.8	7.5			ECA1EM682	50	

Datasheet comparison

- Comparison of datasheets: Panasonic, 25V 100u

Panasonic Aluminum Electrolytic Capacitors/ FC

■ Standard Products Endurance : 105 °C φ4 to φ6.3=1000 h, φ8=2000 h, φ10=3000 h, φ12.5 to φ18=5000 h

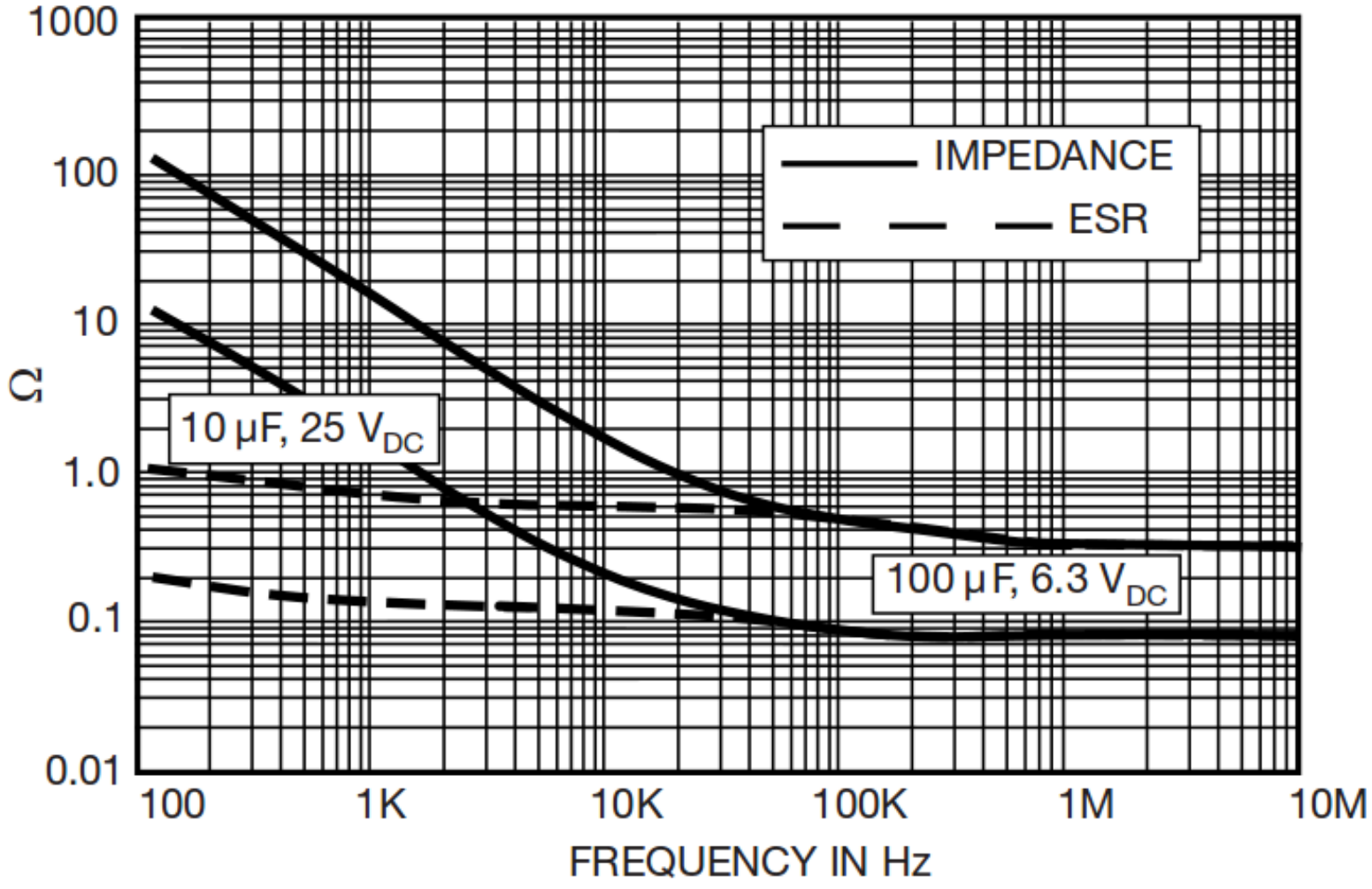
W.V.	Cap. (±20 %)	Case size		Specification			Lead Length				Part No.	Min. Packaging Q'ty	
		Dia.	Length	Ripple Current (100 kHz) (+105 °C)	Imped-ance (100 kHz) (+20 °C)	Endur-ance	Lead Dia.	Lead Space				Straight Leads	Taping
								Straight	Taping *B	Taping *H			
(V)	(μF)	(mm)	(mm)	(mA r.m.s.)	(Ω)	(hours)	(mm)	(mm)	(mm)	(mm)		(pcs)	(pcs)
	10	4	7	65	2.000	1000	0.45	1.5	5.0	2.5	EEAFC1E100( )	200	2000
	22	5	7	120	0.950	1000	0.45	2.0	5.0	2.5	EEAFC1E220( )	200	2000
	27	4	11	120	1.30	1000	0.45	1.5	5.0	2.5	EEUFC1E270( )	200	2000
	39	5	11	175	0.800	1000	0.50	2.0	5.0	2.5	EEUFC1E390( )	200	2000
		6.3	7	200	0.450	1000	0.45	2.5	5.0	2.5	EEAFC1E390( )	200	2000
	47	5	11	175	0.800	1000	0.50	2.0	5.0	2.5	EEUFC1E470( )	200	2000
	56	5	15	235	0.500	1000	0.50	2.0	5.0	2.5	EEUFC1E560( )	200	2000
	82	6.3	11.2	290	0.350	1000	0.50	2.5	5.0	2.5	EEUFC1E820( )	200	2000
	100	6.3	11.2	290	0.350	1000	0.50	2.5	5.0	2.5	EEUFC1E101S( )	200	2000

Solid tantalum capacitors

Generics

- Similar construction with different materials
- Higher C per volume unit, lower ESR
- Operational range T: $-55 \cdots +85$°up to 125°
- Leakage current 0.01 CV, $\tan\delta$ between 0.04 and 0.1, better than aluminium
- Capacitance change with T from ± 15 % to ± 3 %
- Tolerates low reverse polarization
- May fail catastophically (short $\rightarrow$ heat $\rightarrow$ open / fire)
- Chip format for SMD mount

Frequency response



Source: Vishay - Capacitors - Solid Tantalum

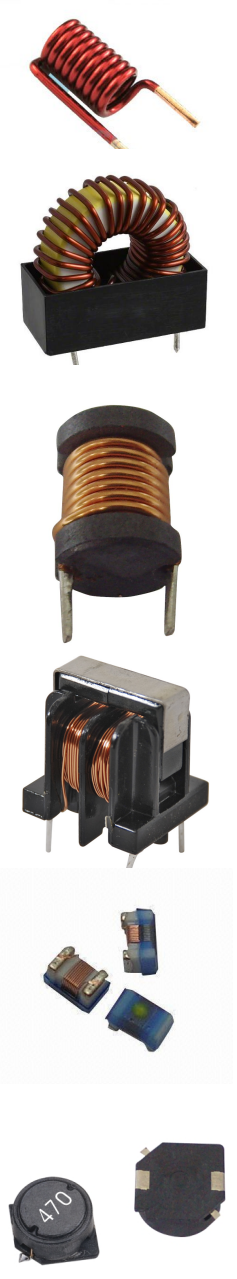
Inductors

Generics

- Capacitors and inductors are energy storage elements
- Capacitors are more ideal

Permeability

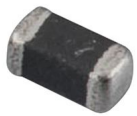
- Inductance is proportional to μ
- High L requires many turns or higher μ
  - High-μ materials have losses
  - Permeability decreases as magnetic field increases. Saturation
  - Changes in molecular structure. Hysteresis
  - μ and losses are temperature dependent



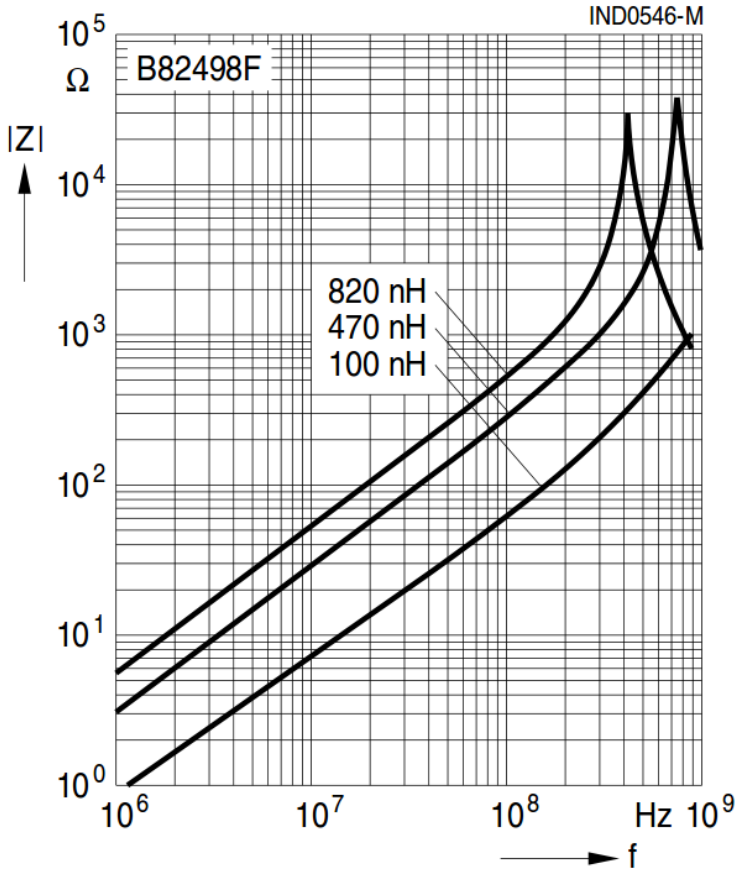
Inductor applications

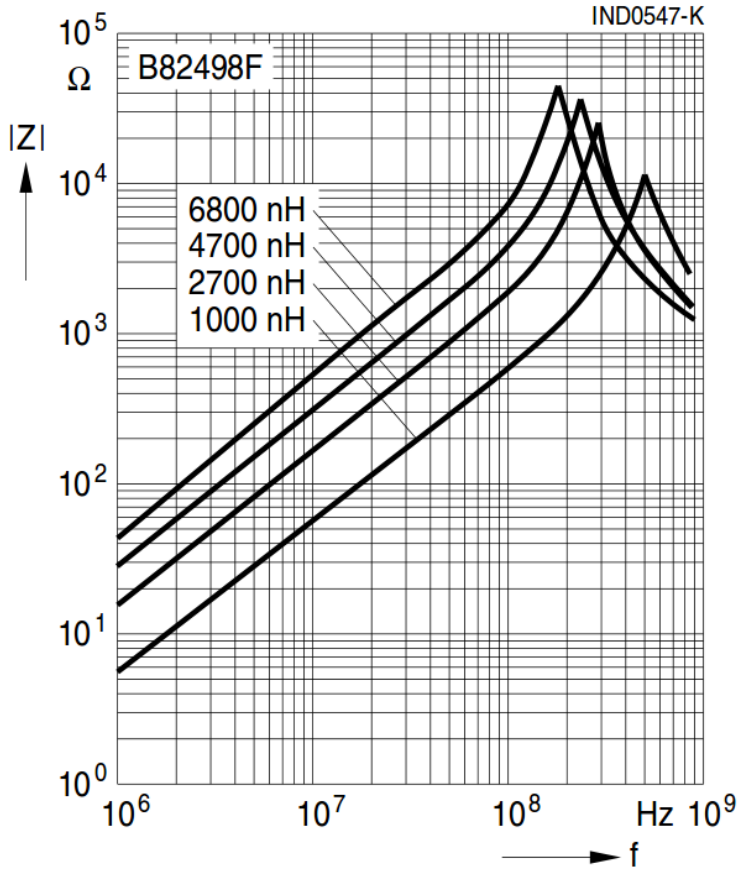
Application fields

- Tuned circuits and filters
  - Predictable performance
  - Low loss, high Q
- Power circuits
  - Energy storage chokes
  - Objective: high volumetric efficiency
  - Saturation is a significant issue
- Suppression
  - Loss is a feature: high loss desirable
  - High loss ferrites
  - Ferrite bead



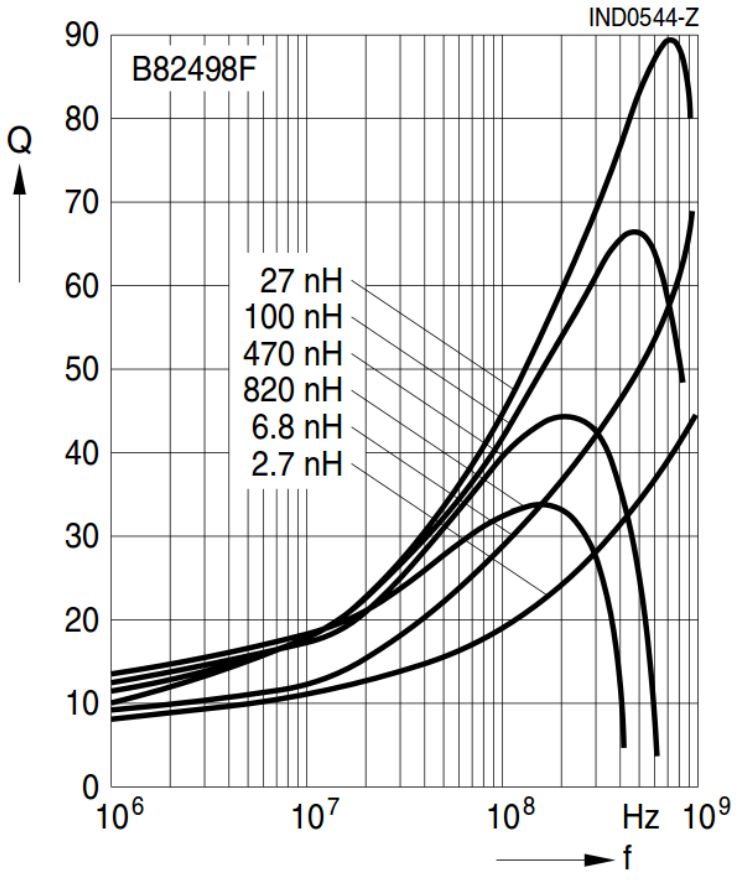
Skin effect and series resonance

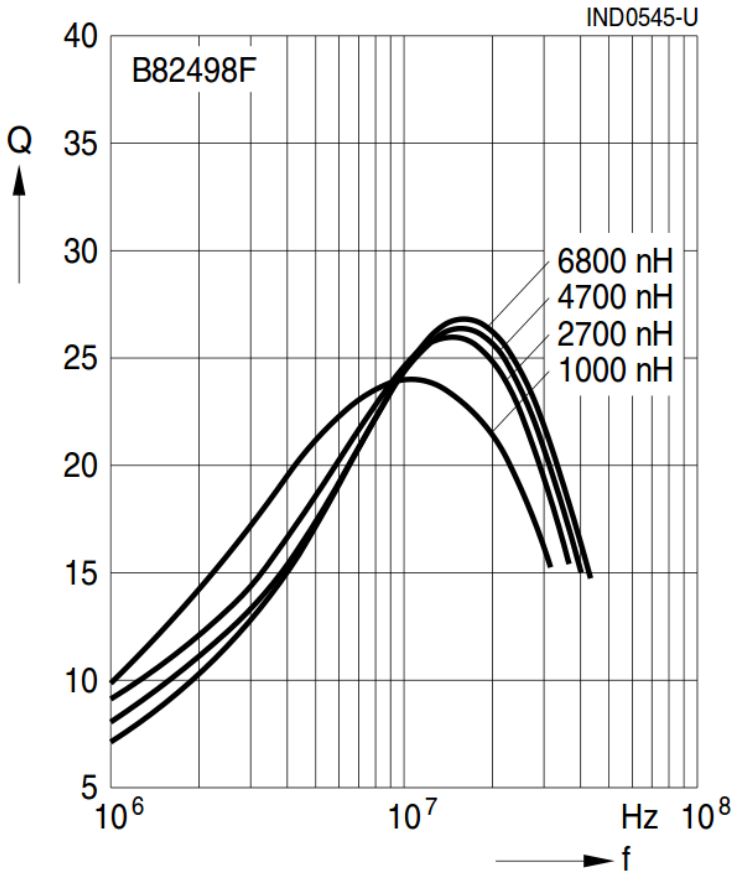




Source: EPCOS SIMID 0805-F

Skin effect and series resonance

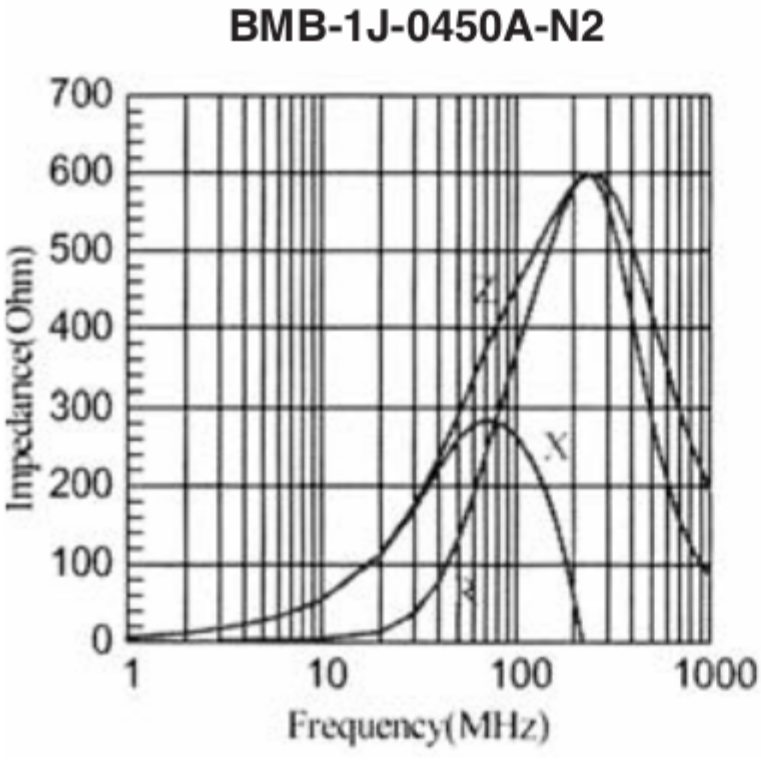


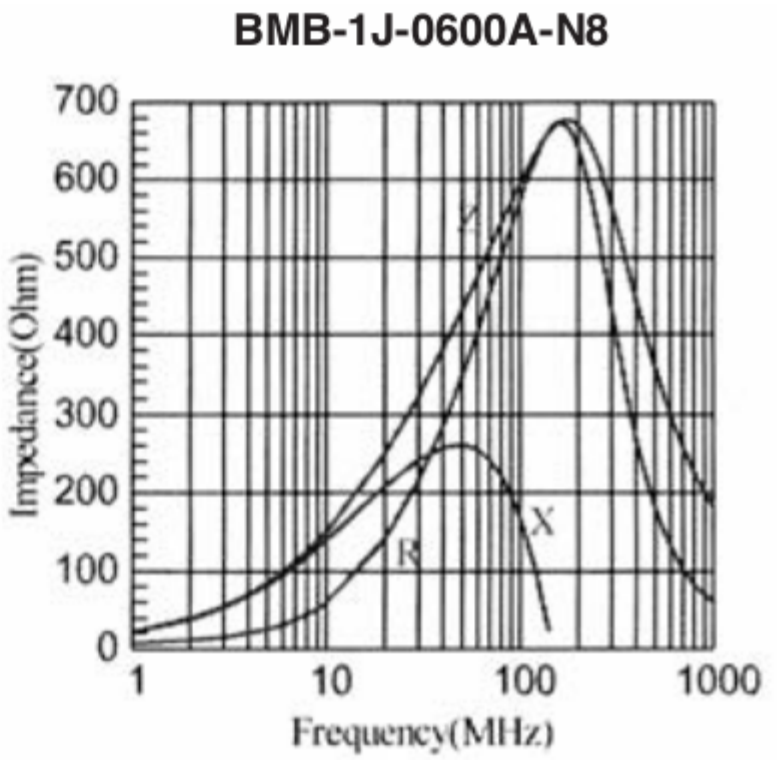


Source: EPCOS SIMID 0805-F

Multilayer chip beads

- To provide significant ac impedance: *AC block*
- 0805 multilayer chip beads example:





Source: TE Connectivity Multilayer Chip Beads