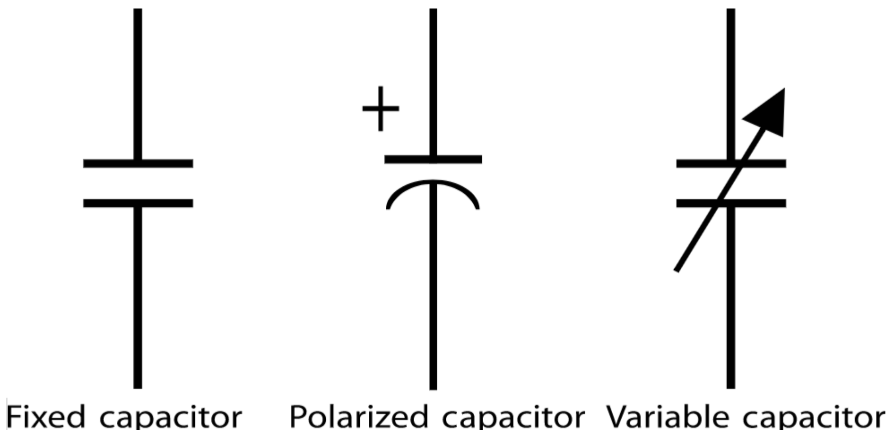
Lecture 9 Capacitors

1. Capacitors

2. Capacitor Modeling

3. Coding Example

1. Capacitors

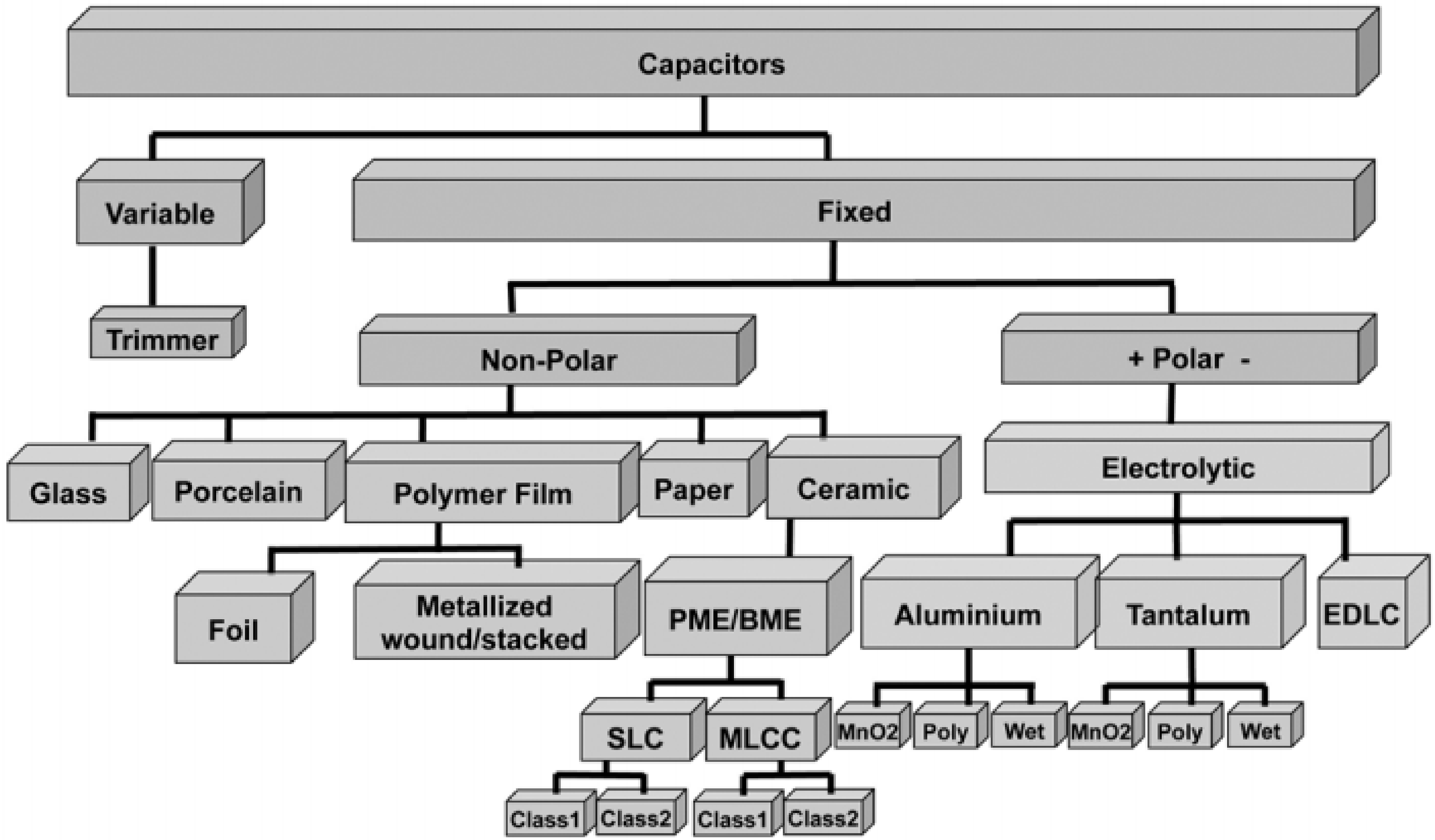


$$C = \frac{Q}{V}$$

$$I(t) = \frac{\mathrm{d}Q(t)}{\mathrm{d}t} = C\frac{\mathrm{d}V(t)}{\mathrm{d}t}$$

$$Z = \frac{1}{j\omega C} = -\frac{j}{\omega C} = -\frac{j}{2\pi fC}$$

Capacitor Types	Features
Ceramic	• Low loss, • Variable ranges, • Leaded/surface mount
Electrolytic	• Higher capacitance value • Low freq. operation, • Long operating life, • Polarized
Tantalum	• Polarized • High value • Leaded/surface mount
Polystyrene/polyester	• Low frequency operation • Low tolerances • Leaded type
Polycarbonate/Polypropylene	• High voltage • High temperature • Self-healing • Leaded
Glass	• Low loss • High RF current


Capacitors
Variable
Fixed
Trimmer
Non-Polar
+ Polar -
Glass
Porcelain
Polymer Film
Paper
Ceramic
Electrolytic
Foil
Metallized wound/stacked
PME/BME
Aluminium
Tantalum
EDLC
SLC
MLCC
MnO2
Poly
Wet
MnO2
Poly
Wet
Class1
Class2
Class1
Class2

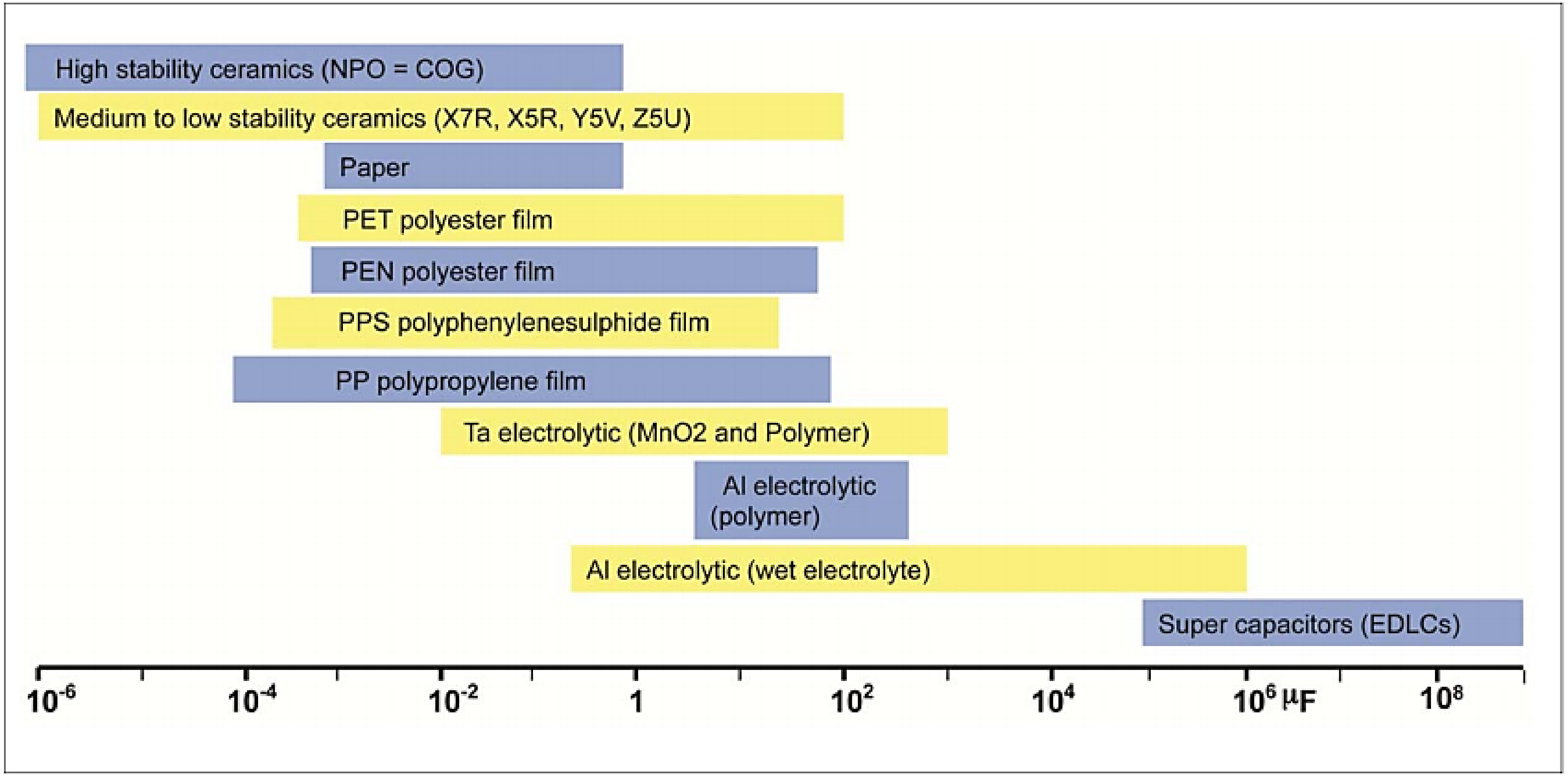


Figure 4: Values of capacitors by dielectric.

1. Capacitors

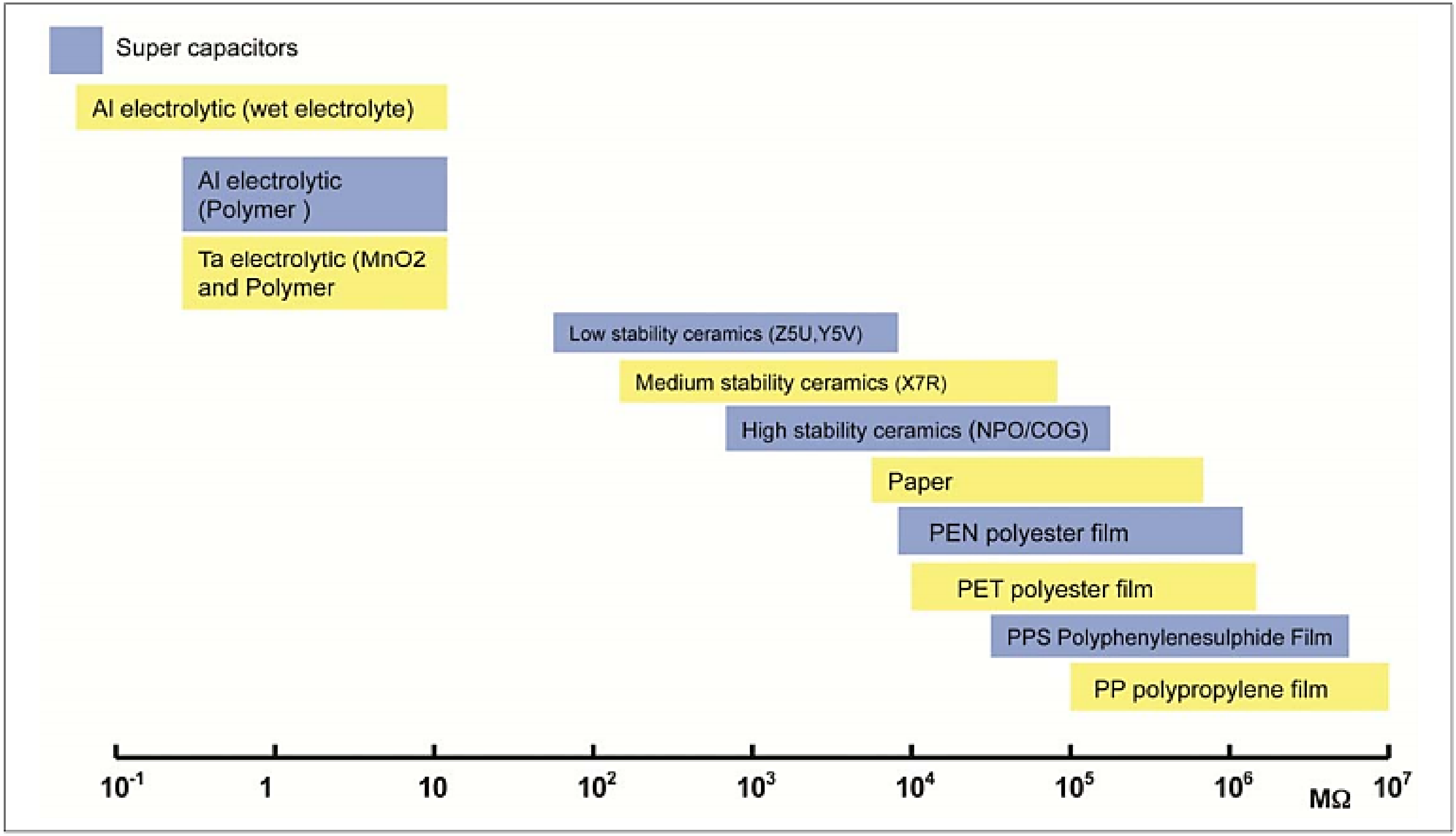


Figure 5: Values of capacitor types relative to dielectric Insulation Resistance (IR).

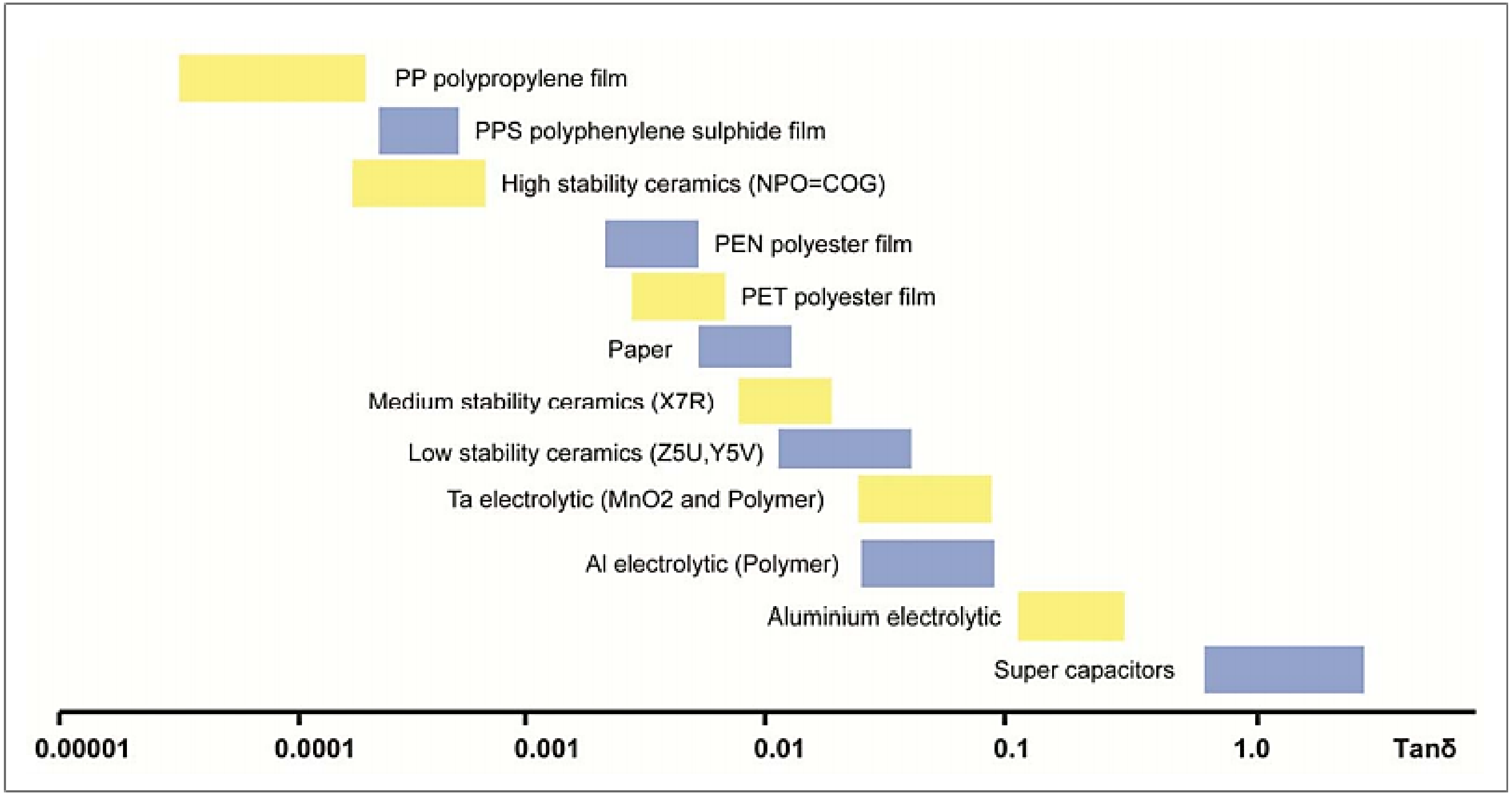


Figure 7: Dissipation factors (Tanδ) of various dielectrics.

Ceramic Capacitors

- Fixed value capacitor in which ceramic acts as a dielectric.
- It is constructed of two or more alternating layers of ceramic and a metal layer acting as the electrodes.
- Ceramic capacitors, especially the multilayer style (MLCC), are the most produced and used capacitors in electronic equipment that incorporate approximately one trillion pieces (1000 billion pieces) per year.
- Ceramic capacitors of special shapes and styles are used as capacitors for RFI/EMI suppression, as feed-through capacitors and in larger dimensions as power capacitors for transmitters.

1. **Multi-layer ceramic capacitors** MLCCs expanded the range of applications to those requiring larger capacitance values in smaller cases. These ceramic chip capacitors were the driving force behind the conversion of electronic devices from through-hole mounting to surface-mount technology in the 1980s.

2. **RFI/EMI** suppression Along with the style of ceramic chip capacitors, ceramic disc capacitors are often used as safety capacitors in electromagnetic interference suppression applications

RFI/EMI suppression ceramic capacitors

Typical ceramic disc capacitor for EMI/RFI suppression for safety standard classes X1/Y2

Ceramic feedthrough capacitor for noise filtering

Multilayer ceramic capacitor (MLCC)

Ceramic power capacitors

- large ceramic power capacitors for high voltage or high frequency transmitter applications.

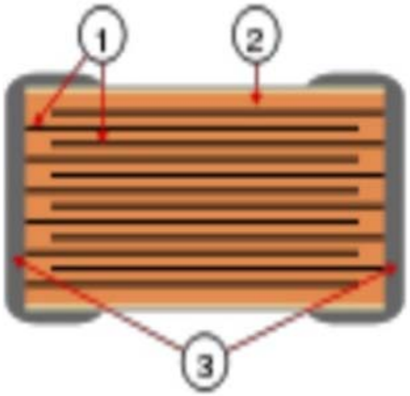
Different styles of ceramic capacitors for power electronic

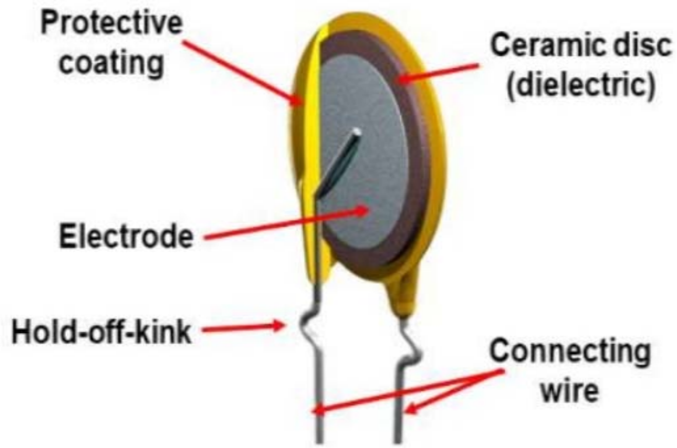
Doorknob style high voltage ceramic capacitor | Disc style power ceramic capacitor | Tubular or pot style power ceramic capacitor

Classes

- **Class 1**
  offer high stability and low losses for resonant circuit applications, are accurate, temperature-compensating capacitors. They offer the most stable voltage, temperature, and to some extent, frequency.
- **Class 2**
  have a dielectric with a high permittivity and therefore a better volumetric efficiency than class 1 capacitors, but lower accuracy and stability for smoothing, by-pass, coupling and decoupling applications
- **Class 3**
  are barrier layer capacitors which are not standardized anymore barrier layer or semiconductive ceramic capacitors have very high permittivity, up to 50,000 and therefore a better volumetric efficiency than class 2 capacitors. However, these capacitors have worse electrical characteristics, including lower accuracy and stability. The dielectric is characterized by very high nonlinear change of capacitance over the temperature range. The capacitance value additionally depends on the voltage applied. Aslo, they have very high losses and age over time.

Construction of a multilayer ceramic chip capacitor (MLCC)



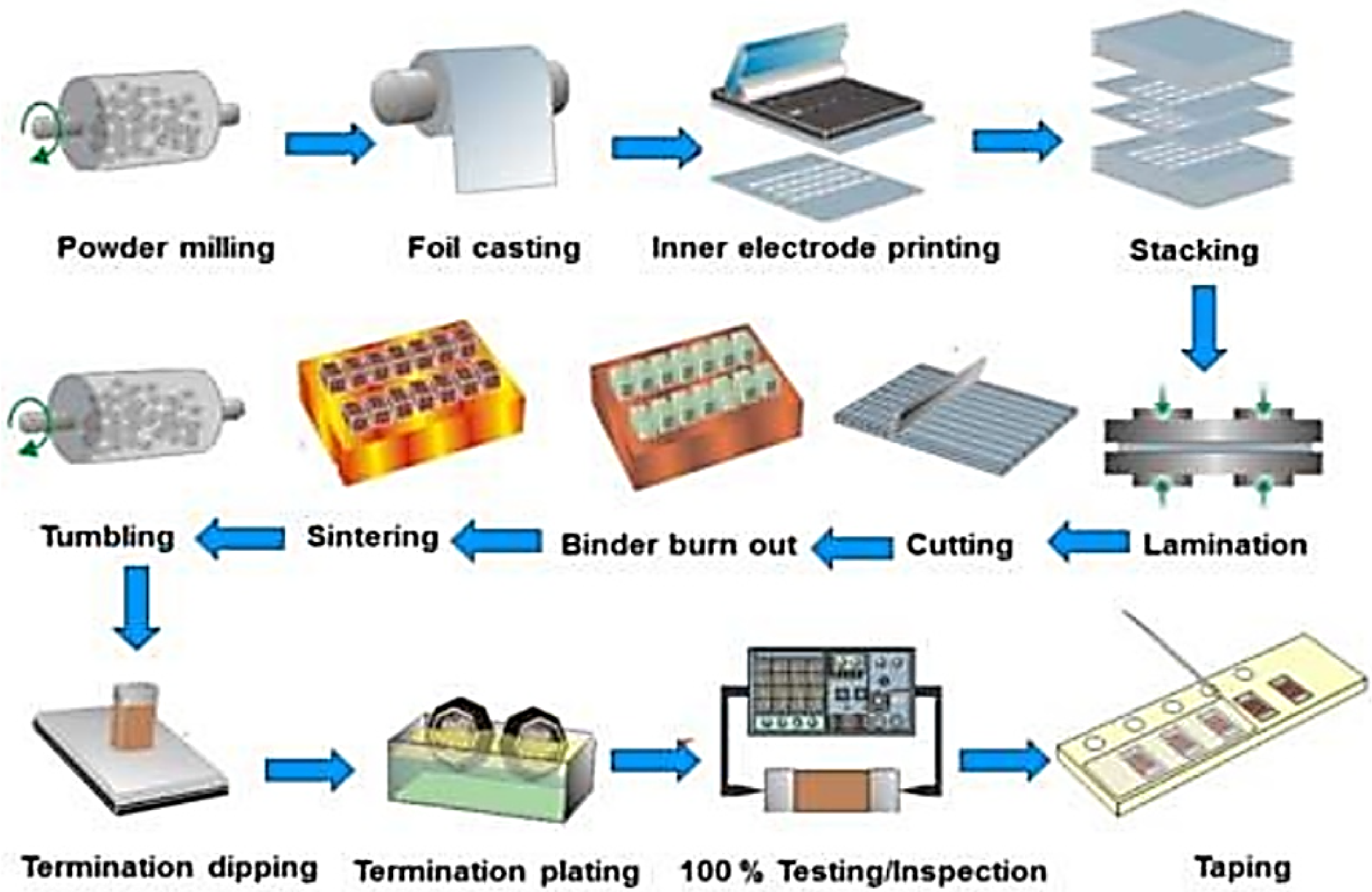


1 = Metallic electrodes
2 = Dielectric ceramic
3 = Connecting terminals

V. Table-2: Various types and features of MLCC

Type	ε value	Loss tangent @100MHz	Features	Applications
Low permittivity	30	0.002	NPO ceramics Excellent temp stability	Oscillator, resonant circuits, filters
Moderate permittivity	1200	0.03	Smaller in size, compa. low cost	Switching circuits
High permittivity	8000	0.1	Poor temp characteristics , higher cap. variation	Bypass

Construction Cycle



Applications

1. **Coupling**
   - Capacitors used in coupling exploit the characteristic of capacitors to only transmit AC components and not transmit DC components, and are used to extract AC components from DC + AC components.
   - As the operating conditions of transistors, ICs and other active elements on circuits vary, it is necessary to extract only the required AC signal after setting the optimal operating conditions for each circuit.
   - Coupling refers to linking circuits together, and, as their name suggests, coupling capacitors act as the Intermediary for linking circuits together.

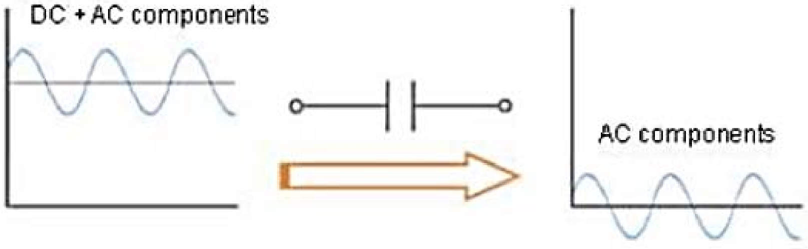


Figure 1. Capacitors for coupling

2. Decoupling

- Power lines on circuits have capacitance and inductance components. If thes components cause the voltage variation on power lines to increase, operation of the circuit becomes unstable. In extreme cases, fluctuations in the power source can become superimposed on the signal line, causing transmission of incorrect signals.
- Decoupling capacitors are used to pass noise coming in from the power source to the ground terminal, while at the same time continuously supplying stabilized current to combat sudden changes in load current on ICs and other circuits.

As shown in Figure 2, even if the noise is superimposed on the line, unwanted noise can be passed to the ground terminal via decoupling capacitors.

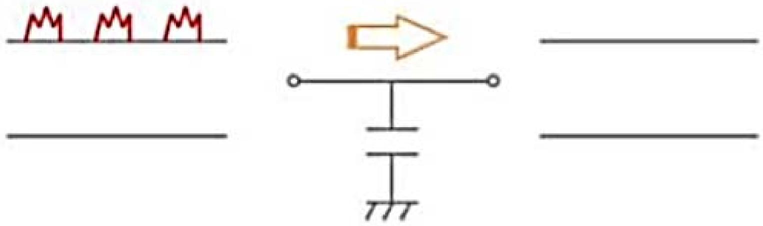


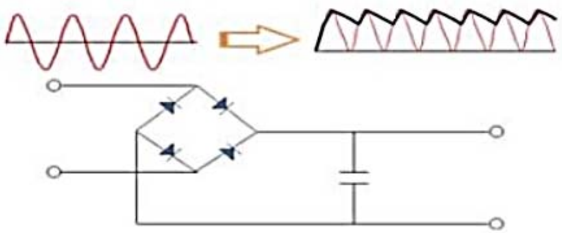
Figure 2. Capacitors for decoupling

3. Filtering

- Capacitors are combined with resistors and inductors to create filters transmit signals of a particular frequency.
- Different filters can be used depending on the frequencies you want to transmit, including low-pass filters that filter out low-frequency components and high-pass filters that filter out high-frequency components.

4. Smoothing

- Smoothing capacitors suppress ripples that are generated even after rectification with a power circuit to smooth-out signals so that they approach direct currents.
- When smoothing capacitors are installed after rectification, excess voltage is stored in the capacitor during high-voltage periods and released during low-voltage periods, thereby eliminating fluctuations in voltage.



Advantages

- Non-Polar-Some kinds of capacitors, such as those that use an aluminum oxide insulator, develop a polarity, where one metal plate prefers negative charges and the other prefers positive charges. In direct current (DC) circuits, you know which sides are positive and negative, but in alternating current (AC) circuits, polarity is a problem. To their advantage, ceramic capacitors have no polarity; they work well in either AC or DC circuits.

- High Voltage-The thin, insulating layer in a capacitor can break down and conduct if a circuit puts too much voltage across it. This can destroy the component. Ceramic materials stand up to higher voltages than other insulating materials like plastics or aluminum oxide. Circuits that handle hundreds to thousands of volts typically use ceramic capacitors.

Disadvantages

- Different insulating materials, called dielectrics, tend to have a range of capacitance values in which they work best. Because of the way manufacturers make them, ceramic capacitors generally have values less than 1 microfarad. If an electronics designer needs capacitors with values more than that, he tends to avoid ceramics and use tantalum or aluminum electrolytic types.
- Microphonic- Some ceramic capacitors pick up mechanical vibrations like a microphone, turning them into unwanted electrical signals. Squeezing or vibrating the ceramic produces a small voltage in the capacitor. If the circuit's environment has strong vibrations, extra care in design can minimize the microphonic effect.

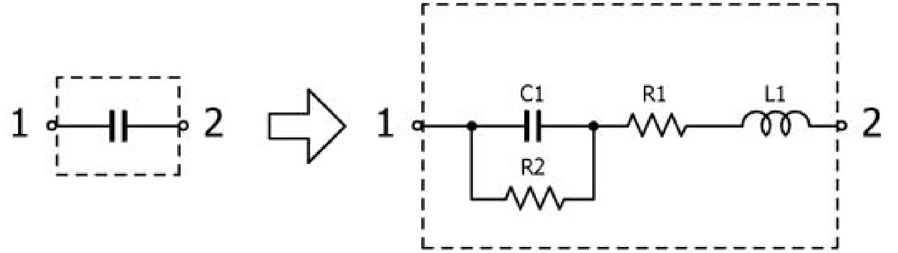
TDK Equivalent Circuit Model Library

Multilayer Ceramic Chip Capacitors

Commercial Grade, High Temperature Application / C4532 series

July 26, 2019
Simple Model

Circuit Diagram



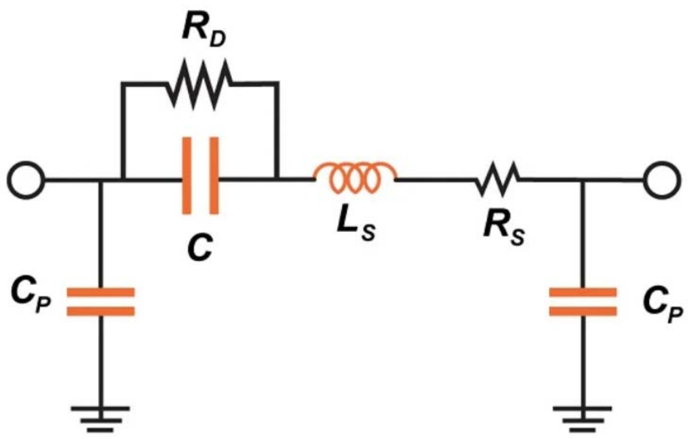
Circuit Parameters

Part No.	C1[pF]	L1[nH]	R1[ohm]	R2[Gohm]
C4532NP02J333J200KA	33,000	0.700	0.0076	10.0
C4532NP02E104J320KN	100,000	0.700	0.0051	5.00

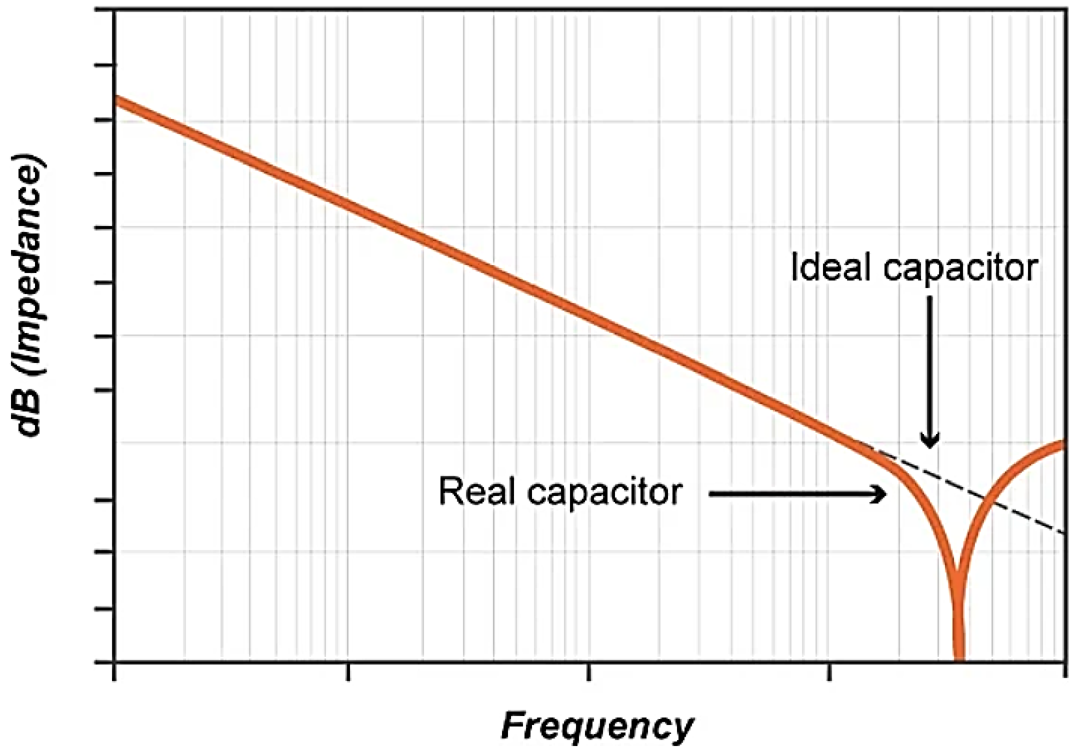
Table-3 Typical frequency response of chip capacitor

Frequency (MHz)	Equivalent Value
20	99 pF
40	103 pF
80	112 pF
120	133 pF
160	181 pF
200	318 pF
240	**Short**
280	1.14 nH
320	1.89 nH

The above example shows that particular chip can be employed only below 240 MHz.



R_D
C
L_S
R_S
C_P
C_P

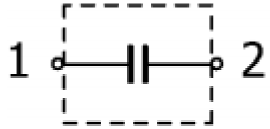


Ideal capacitor
Real capacitor
dB (Impedance)
Frequency

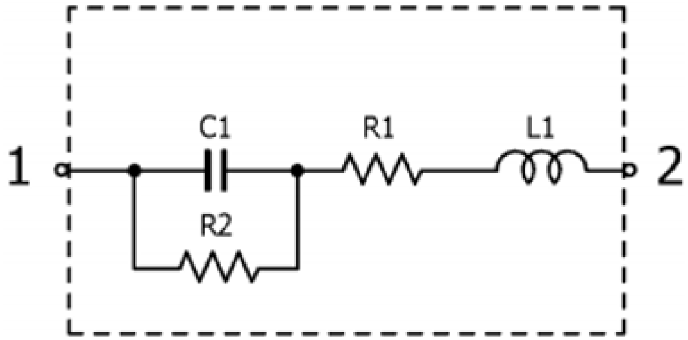
3. Coding Example

1. Calculate the impedance of the following capacitos. Write a Python code calculate impedances of capacitors 1 and 2 at f = 10 kHz, 100 kHz, 10 MHz, and 1000 MHz. Run the code and show the result.

Capacitor 1: An ideal capacitor, C = 33000 pF



Capacitor 2: A real capacitor



C1[pF]	L1[nH]	R1[ohm]	R2[Gohm]
33,000	0.700	0.0076	10.0

Fin

(End)