BE1M13VES

Manufacturing of Electrical Components

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Overview

TOPIC

Capacitors

Parameters:

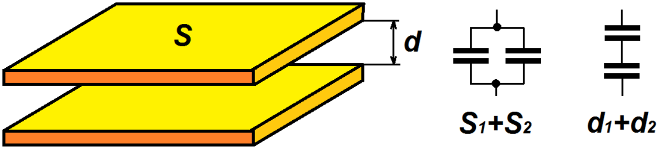
- C... capacitance
- δ... tolearance
- U... nominal voltage
- D... dissipation factor
- ESR... equivalent series resistance
- TCC... temperature coeficient of capacitance
- VCC... voltage coeficient of capacitance
- frequency dependence

Capacitance of Capacitors

Capacitance:

$$C = \epsilon_0 \cdot \epsilon_r \cdot \frac{S}{d}$$

- ϵ_0 ... is the electric constant ($\epsilon_0 \approx 8.854 \cdot 10^{-12}$ F/m),
- ϵ_r ... is the relative static permittivity,
- S ... is the area of overlap of the two plates,
- d ... is the separation between the plates.

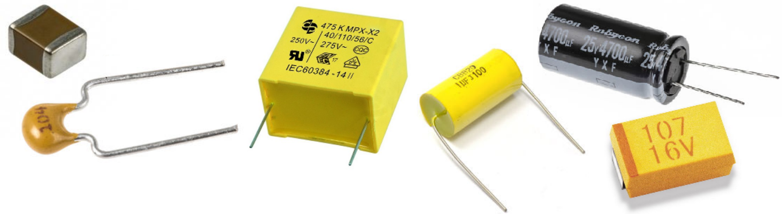


TOPIC

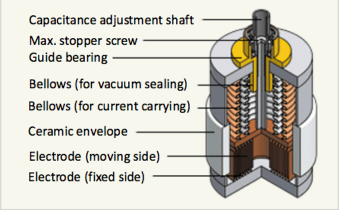
Technology Overview

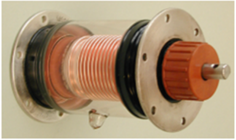
Technologies are derived from dielectric material:

- Air, vacuum capacitors
- Ceramic capacitors (NP0, X5R,...)
- Film (foil) capacitors (paper, PP,...)
- Electrolytic capacitors (Al_2O_3,...)



Vacuum Capacitor



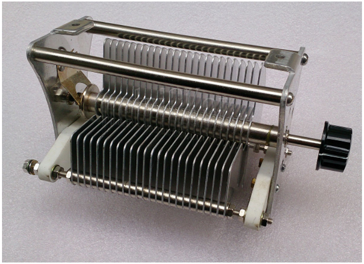


Source: renosubsystems.com/plasma-etching-deposition-technologies/rf-matching-networks/

- Electrodes (stator and rotor) are very similar to air capacitors.
- Advantageous is higher insulation capability. Maximum applied voltage is given just by auto-emission of electrons between stator and rotor parts.
- Most widespread design is vacuum tube similar to electron tubes. Most critical is hermetic sealing (glass tubes).
- Low power dissipation.

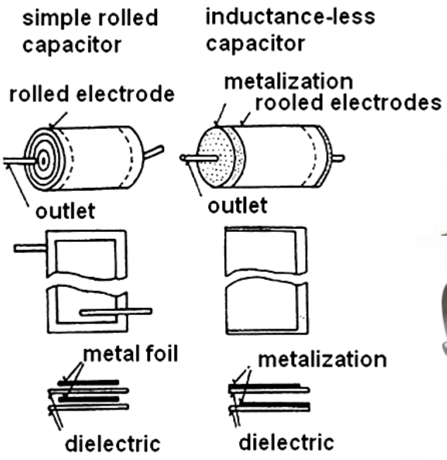
Air Capacitor

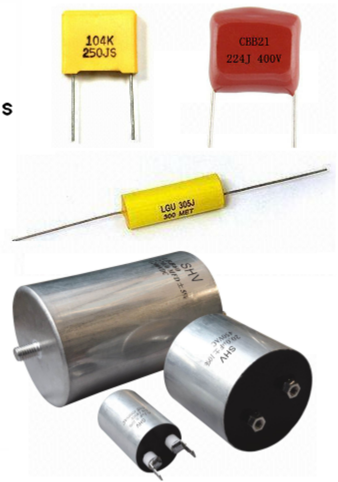
- They are created with a set of metal plates separated with an air dielectric.
- Power losses are negligible.



- They are used as tuning and variable capacitors.
- Maximum applied voltage is given just with the air-isolation capability.

Foil Capacitors



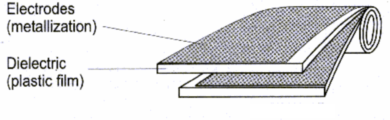


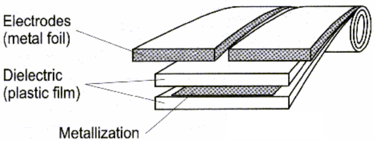
Foil Capacitors

dielectric dry paper for capacitors (natron-celluloze) from 6 to 20 μm thickness, typically 2 layers. Plastic foils: polystyrene, polyethylentherepthalath (PETP), polycarbonate, polyimide, polypropylene,

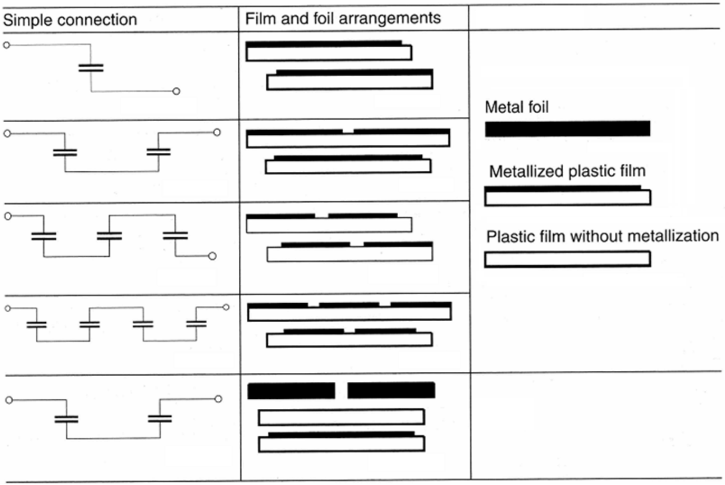
electrodes aluminum foil, thickness - units of μm,

leads copper pads bonded directly on electrodes, copper wires rolled into bulk of capacitor.





Arrangement for high voltage



Ceramic Capacitors

Ceramic material with relative permittivity from range 1 (linear) up to 10^4 (ferroelectric) is used for dielectric layer. Conductive surface of electrodes is made from silver. Silver is deposited by evaporation.

- **the oldest ceramics (1930):** were based on oxides of titan and manganum ($\epsilon_r = 10 - 100$, TCC from -750 to $100 \cdot 10^{-6}\ {}^\circ C^{-1}$).
- **titan based ceramics:** ($BaTiO_3$, $CaTiO_3$, $SrTiO_3$, $MgTiO_3$) have ϵ_r in range 1000 - 20000 but they are ferroelectric - exhibit Curie's temperature, dielectric hysteresis and they are voltage dependent.

Ceramic Capacitors - Types

capacitor called „class 1“:

- stable and linear ϵ_r,
- low power loss: D factor at maximum $2 \cdot 10^{-3}$,
- TCC from -680 to $200 \cdot 10^{-6}\ {}^\circ\mathrm{C}^{-1}$,
- voltage independent.

Commercial names:
STEALIT (similar to porcelain), STABILIT, TEMPA, RUTILIT, KONDENSA, NEGALIT.
Typically contain TiO_2, MgO, ZrO_2. Such capacitors are good for high frequency and high voltage applications.

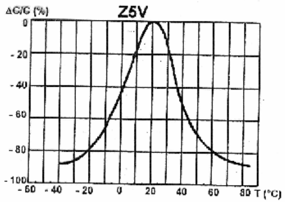
Ceramic Capacitors - Types

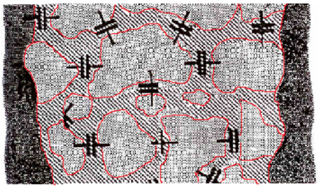
capacitor called „class 2“:

- dielectric with high ϵ_r,
- ferroelectric features (voltage dependent),
- very temperature sensitive. Peak of maximum ϵ_r can be shifted by additional oxides ($SrTiO_3$, $PbTiO_3$, $BaSnO_3$, $CaSnO_3$) or flatten ($CaTiO_3$, Bi_2SnO_3).

Commercial names:

PERMITIT ($BaTiO3$, D max. $3 \cdot 10^{-2}$, tolerance $\pm 50\%$). Suitable for coupling and filtering capacitors.





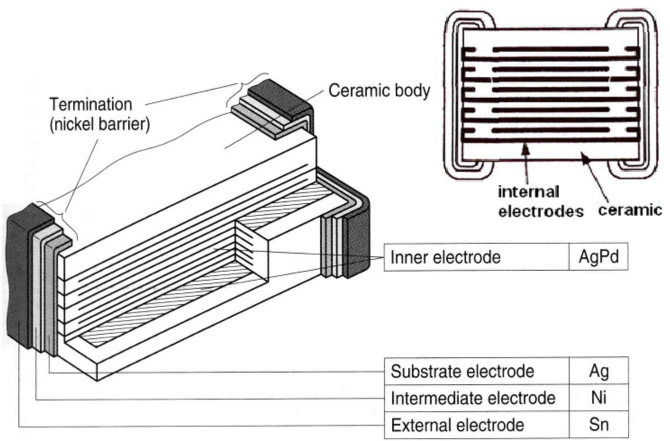
Ceramic Capacitors - Types

capacitor called „class 3“:

- dielectric with high ϵ_r,
- similar ceramic as for „class 2“ but different burning process (re-oxide ceramic),
- large power loss, due to high electrical strength in ferroelectric, ceramic exhibit some „semiconductor“ behavior,
- Material has a domain structure - ferroelectric properties again.

Commercial names:
SUPERMIT, SIBATIT (ϵ_r approximately $5 \cdot 10^4$).
These capacitors are not high-quality devices, ideal for low-cost application.

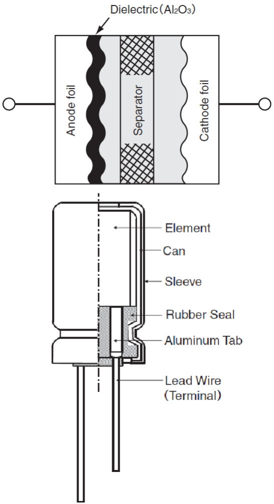
Mechanical Design - SMD



Electrolytic Capacitor

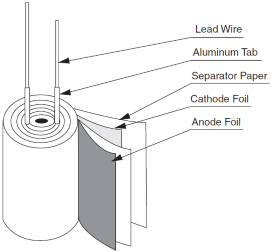
Dielectric: created by a very thin oxide layer placed on one side of electrode. Thickness allows to achieve large capacity in a small volume. Disadvantageous is a polarization of oxide layer.

Design: aluminum electrolytic capacitors are similar to rolled capacitors. Rolled electrodes are made of aluminum strip. Surface is enlarged by brushing and finally is etched. Dielectric layer is formed by anodic oxidation process. Rolled strips are impregnated by electrolyte.



Features

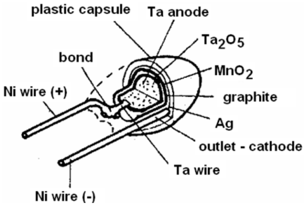
- High capacity due to small insulation thickness and large surface,
- only one polarity,
- relatively small maximum nominal voltage:
  - Aluminum (Al_2O_3) up to 500 V
  - Tantalum (Ta_2O_5) up to approximately 50 V (100 V)



Aluminum Electrolytic Capacitors:

They have similar design to foil capacitors. Anode and Cathode is made of Aluminum. Part of the cathode is made by electrolyte (acid H_3BO_3).

Tantalum Electrolytic Capacitors



- Higher capacity due to very small insulation thickness
- Better ESR - Equivalent Serial Resistance
- Smaller breakdown voltages

Anode: Made from burned Ta powder, then oxidized in H_3PO_4

Cathode: Capacitors with liquid electrolyte have hermetic Ag capsules (cathode). Acid H_2SO_4 is used as electrolyte. Capacitors with solid electrolyte don't have hermetical capsule, MnO_2 is used as electrolyte, cathode is made from colloidal graphite and silver.

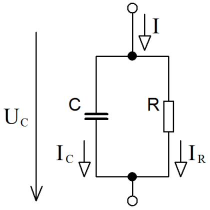
TOPIC

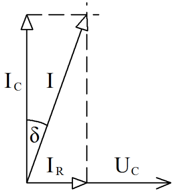
Power Dissipation Factor

$$D = tg\delta = \frac{P_{loss}}{Q} = \dots$$

For parallel scheme (figure)

$$\dots = \frac{I_R}{I_C} = \frac{1}{\omega CR}$$





Dissipation factor describes the total power losses in dielectric at AC supply. Dissipation factor includes all losses in dielectric material and ohmic losses in wire outlets and electrodes.

Temperature and Voltage Dependency

- Similar description as for resistors via TCC (Temperature Coefficient of Capacitance):

$$C = C_0 \cdot (1 + TCC \cdot (T - T_0))$$

and via VCC (Voltage Coefficient of Capacitance):

$$C = C_0 \cdot (1 + VCC \cdot (T - T_0))$$

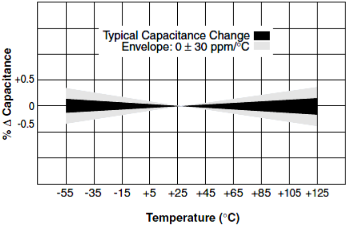
- It can be considered linear in case of foil capacitor or ceramic capacitor of class 1. The TCC is very small.
- TCC is very high and dependent on temperature in case of ceramic capacitors of class 2 and 3.
- Quite strong dependency is also in case of Electrolytic capacitors.

Temperature Dependency - Ceramic Capacitors

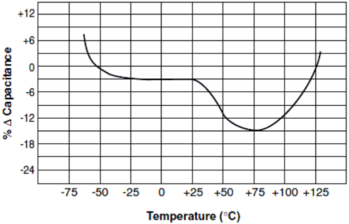
EIA-198 TC CODES FOR CLASS II, III & IV CERAMIC DIELECTRICS					
Alpha Symbol	Low Temperature °C	Numeric Symbol	High Temperature °C	Alpha Symbol	Max Cap Change Over Temp Range %
Z	+10	2	+45	A	±1.0
Y	-30	4	+65	B	±1.5
X	-55	5	+85	C	±2.2
		6	+105	D	±3.3
		7	+125	E	±4.7
		8	+150	F	±7.5
		9	+200	P	±10
				R	±15
				S	±22
				T	+22 to -33
				U	+22 to -56
				V	+22 to - 82

Temperature Dependency - Ceramic Capacitors

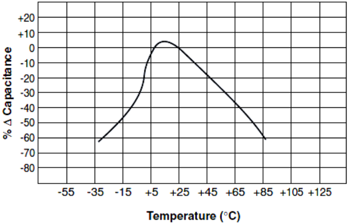
NPO - Temperature Coefficient



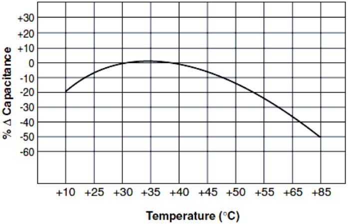
X7R - Temperature Coefficient



Y5V - Temperature Coefficient



Z5U - Temperature Coefficient



Voltage Dependency - Ceramic Capacitors