Chapter 11: Passives: Discrete, Integrated, and Embedded

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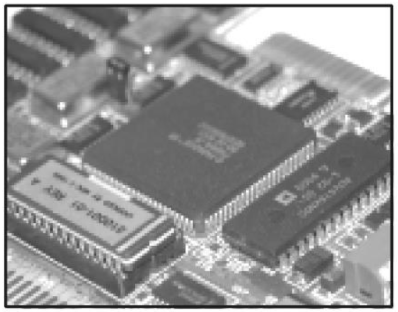
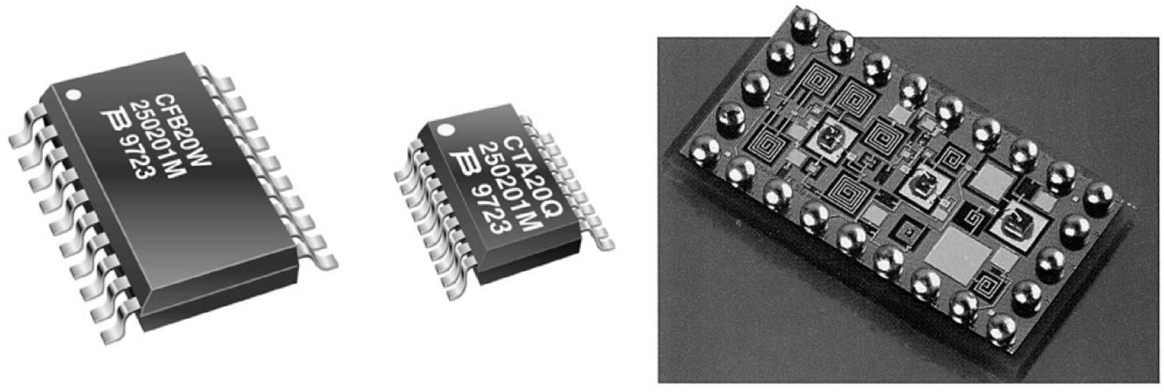
Types of Passive Components

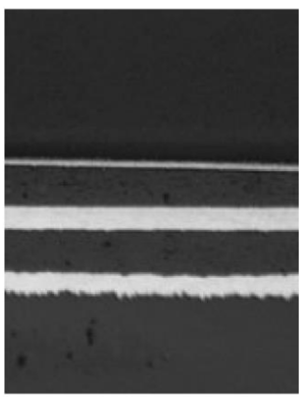
(a) Discretes



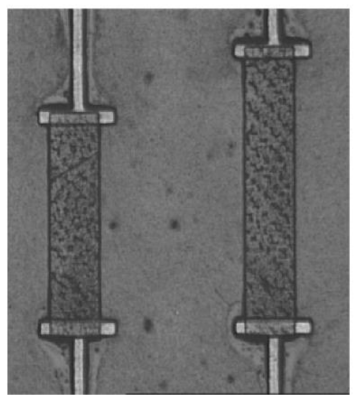
(b) Integrated passive devices (IPD)



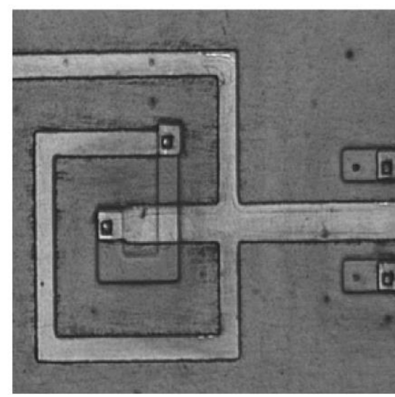
(c) Embedded Capacitor



(d) Embedded Resistor



(e) Embedded Inductor



(c-e): Integral substrate with embedded polymer/ceramic nanocomposite capacitor, epoxy/carbon resistor, and copper spiral inductor fabricated on a PWB substrate.

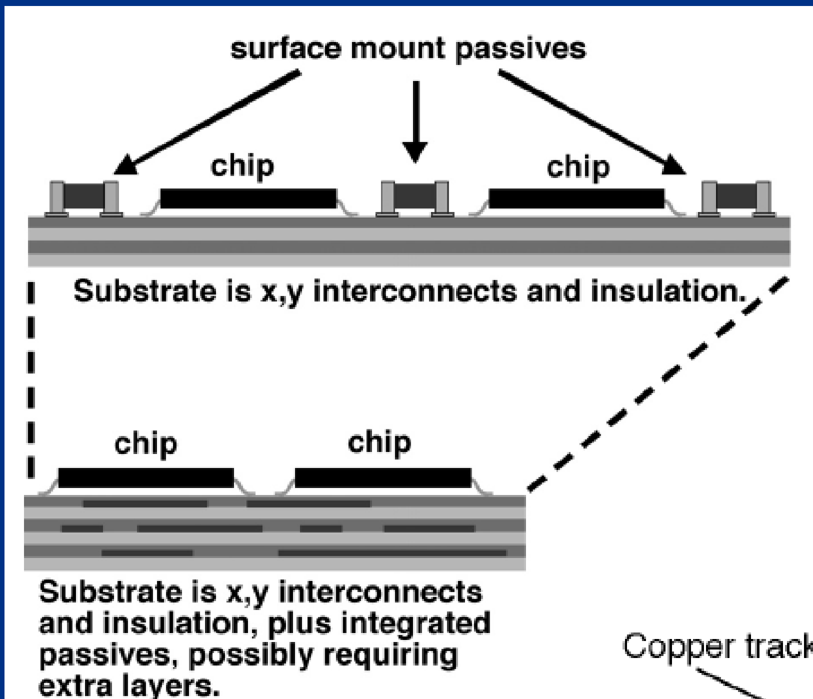
Embedded passive devices: advantages

- **Reduced system mass, volume and footprint.**
  - Individual packages are eliminated and passives can go “underground,” leaving more room on the surface for ICs.
- **Improved electrical performance.**
  - Integrated passives can have lower parasitics, particularly, much lower inductance in capacitors.
    - Due to the elimination of leads and the shorter connections between passive components and other IC chips.
- **Increased design flexibility.**
  - The component’s resistance, capacitance, or inductance can be sized to any desired value within the technology’s range.
- **Improved reliability.**
  - Solder joints are eliminated.
- **Reduced unit cost.**
  - Integrated passives can be formed simultaneously and with very low incremental cost. Also, they are inherently lead-free.

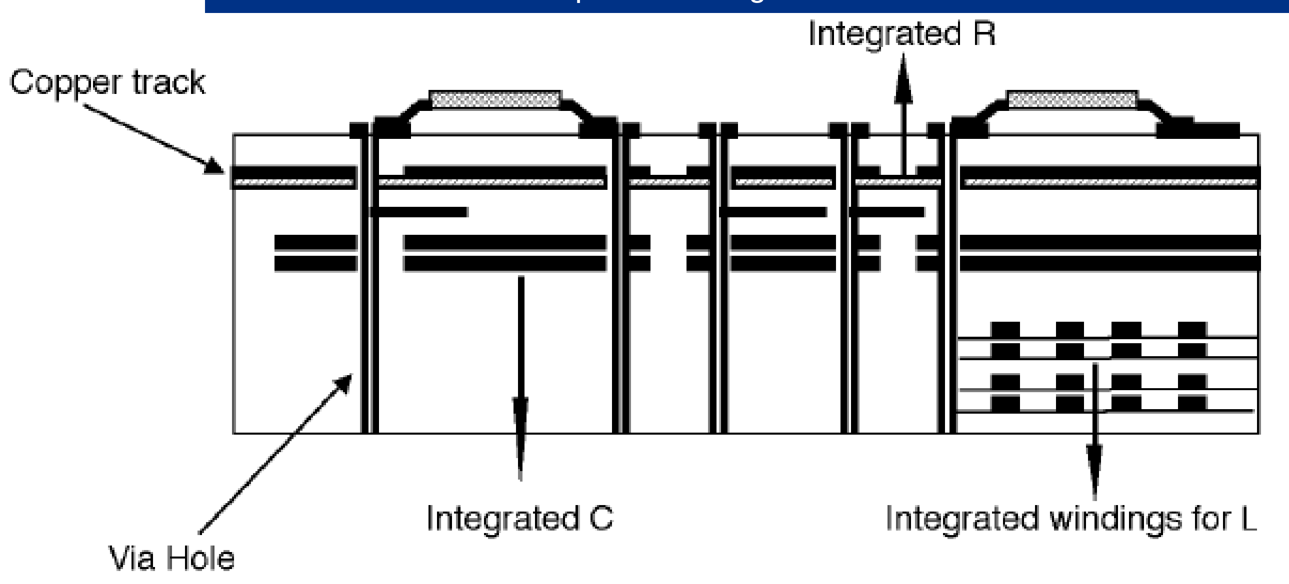
Embedded passive devices: problems

- **Problems regarding materials and processes**
  - New materials, processes and test systems are required.
- **Lack of design tools**
  - for both component sizing and system layout.
- **Requires vertical integration**
  - The same company must manufacture both substrates and passives.
- **Yield issues**
  - One bad component can lead to scrapping the entire board.
- **Tolerance issues**
  - Integrated passives cannot be presorted prior to inclusion on the board.
- **Lack of standardization**
  - The various segments of the integrated passive industry aren't speaking the same language
- **Surface-mount technology is improving**
  - moving towards 01005
- **Lack of costing models**
  - It is not easy to tell when integrated passives might be more cost effective.

Embedded passives

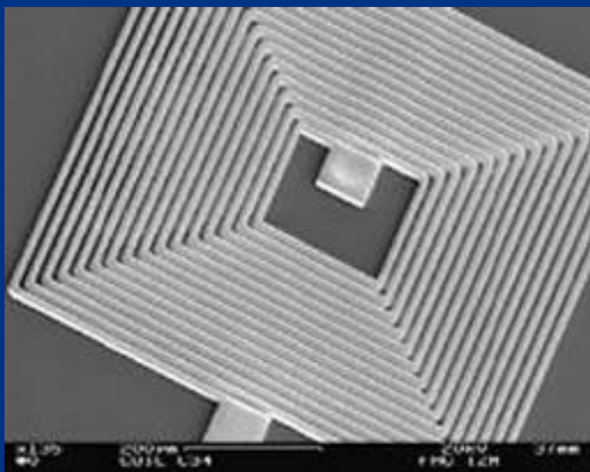


Passive components integrated into MCM substrate

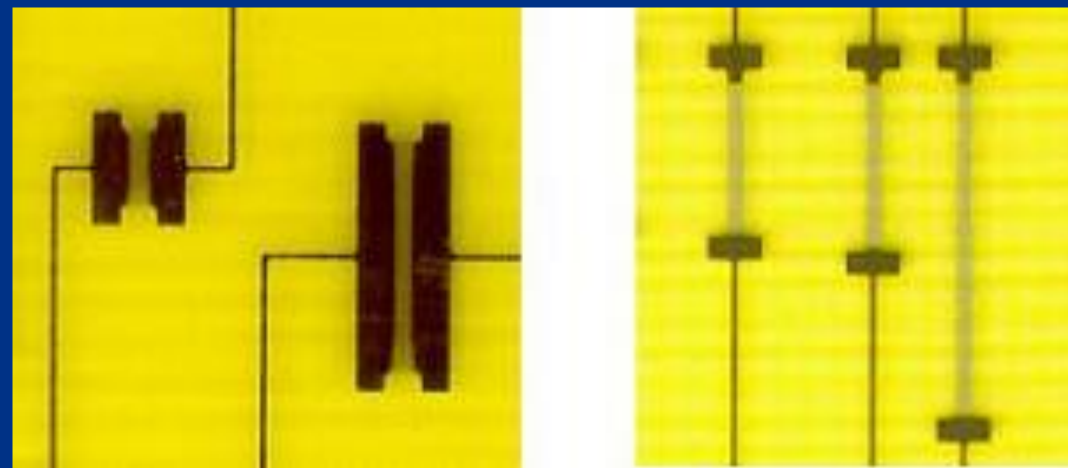


Embedding means miniaturization

Embedded passives



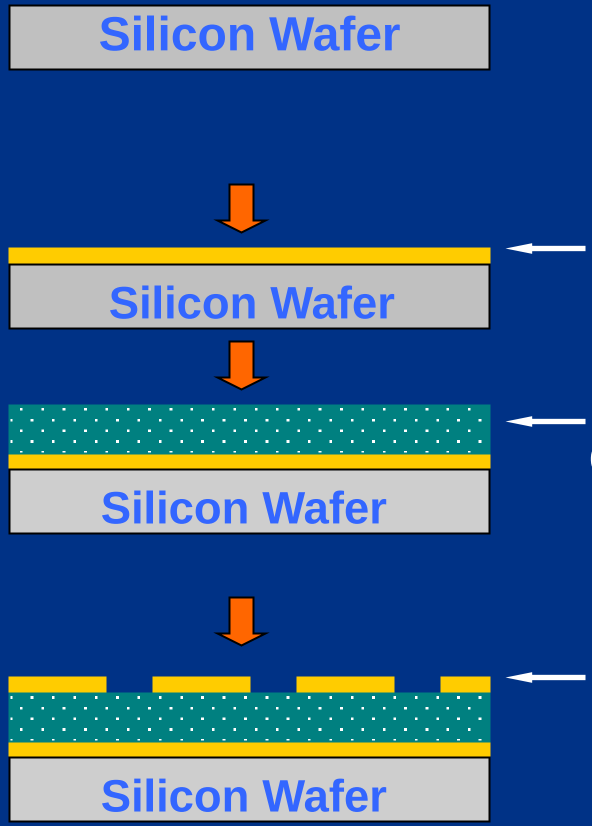
Inductor



80-20,000Ω *inSite*™ Embedded resistors

Embedded resistor

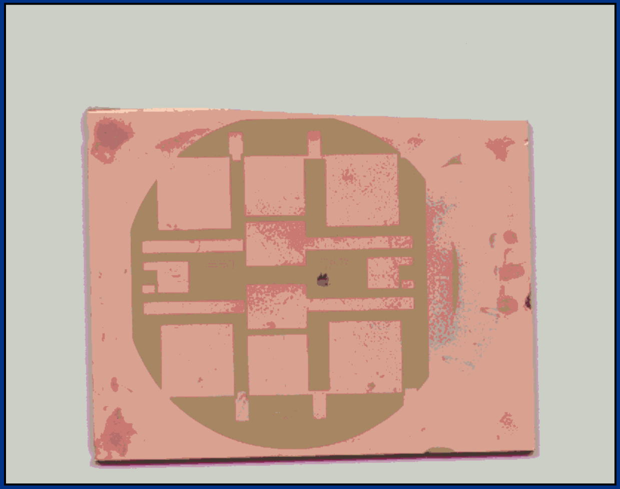
Capacitor prototype fabrication



dc-sputtering Au
(bottom electrode)

Spin-coating
dielectric material

dc-sputtering Au
(top electrode)



Pros and cons of embedding passives

Benefits

- Smaller board area, low weight and profile.
- Less parasitics and more suitable for high frequencies.
- Lower energy consumption.
- Higher assembly yield and lower assembly costs.
- Shorter signal paths and less wiring density required.

Challenges

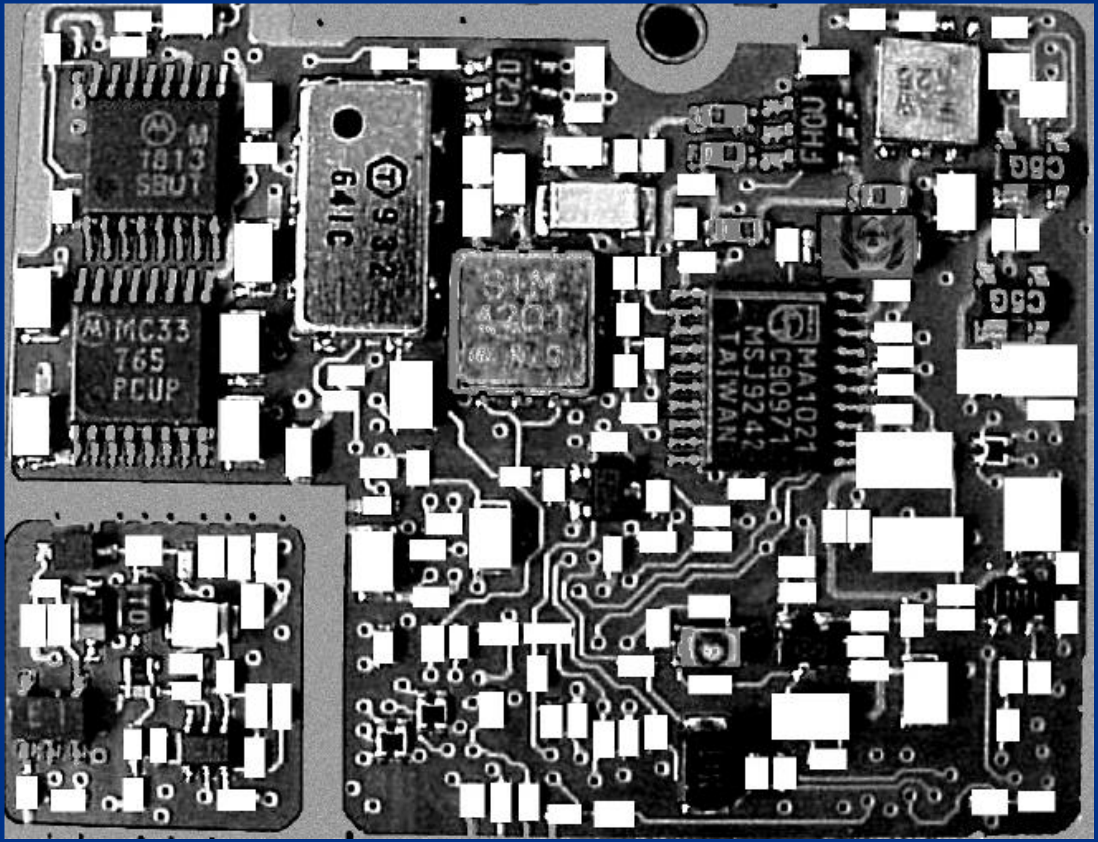
- More complex design in 3-D.
- Low temperature fabrication process compatibility.
- Reduction of manufacturing cost required.
- Thermomechanical reliability.
- Board manufacturing complicated and yield too low.
- Crosstalk in high density packaging.

But why bother about passives?

- Passive components are key functional elements of all electronic systems . . .
- . . . and substantially influence system cost, size and reliability . . .
- . . .hence, providing increased functionality and/or miniaturization options

A typical circuit board contains 80% passive components mounted on 50% of the board area.

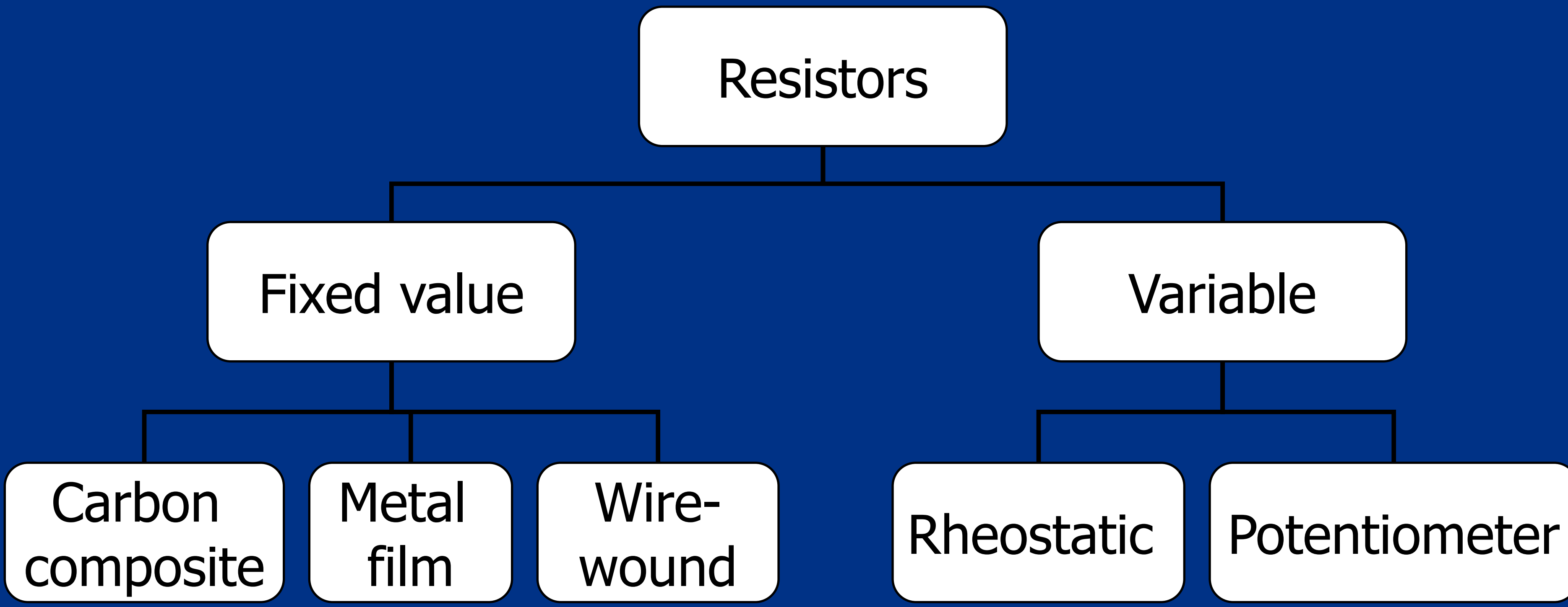
Passives in Nokia 6161 cell phone



Cell phone board (part of the board) showing the footprints of surface mount passive components marked in white

[Integrated Passive Component Technology, Edited by R.K. Ulrich and L.W. Schaper, ISBN 0-471-24431-7, 2003].

Resistor technology

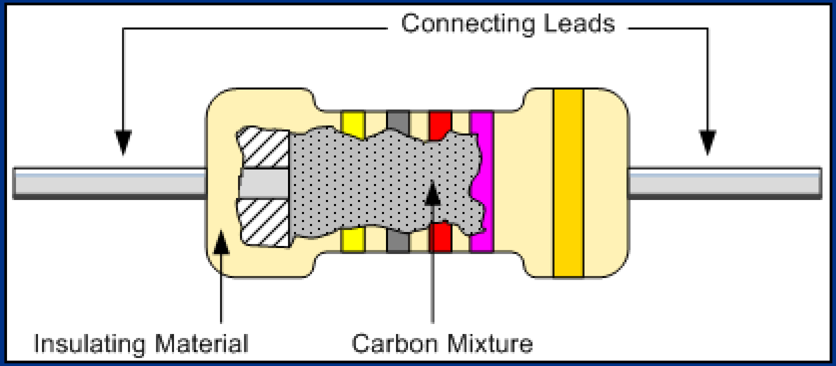


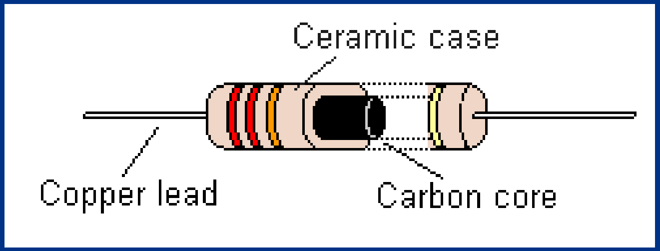
Passives can be through hole mounted, surface mounted or printed

Fixed resistors

- ***Molded carbon composite***
  - Use a mixture of carbon powder with a polymer binder.
  - 0.1 Ω -10 G Ω, 5-20 %,<2 W,
  - Cheapest!
- ***Wire wound***
  - Formed from windings of fine wires. (CrNi, CuNi on ceramic core)
    - The resistance alloy is winded on an insulator form, and then inserted in a ceramic case.
  - 10 Ω -100 k Ω, <0,5 %,
  - Very stable but get hot!
- ***Film layer***
  - Use carbon or metal film deposited on a substrate (carbon, metal, -oxide thick film on ceramic base)
  - 1 Ω -1 G Ω, 0.1 - 5 %,
  - Metal film well is suited for HF

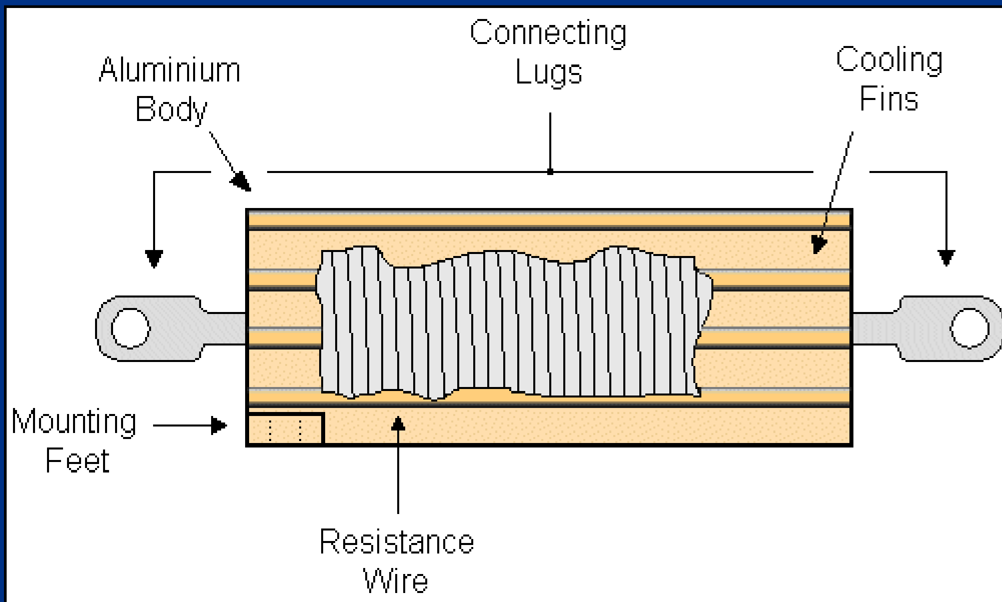
Carbon composite resistors

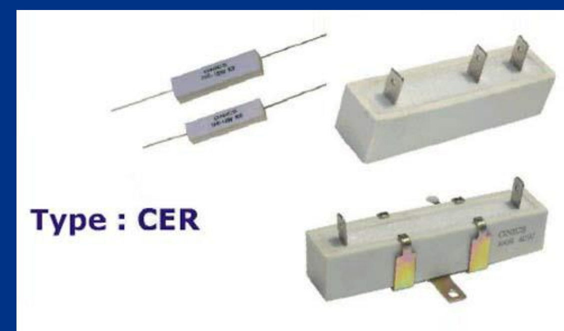




- Inside a carbon resistor is a 'core' of compressed graphite surrounded by ceramic with copper 'leads' coming out the ends (to allow soldering).
- The degree of compression, the length of the core and additives (such as clay) determine the resistance of the 'core'.

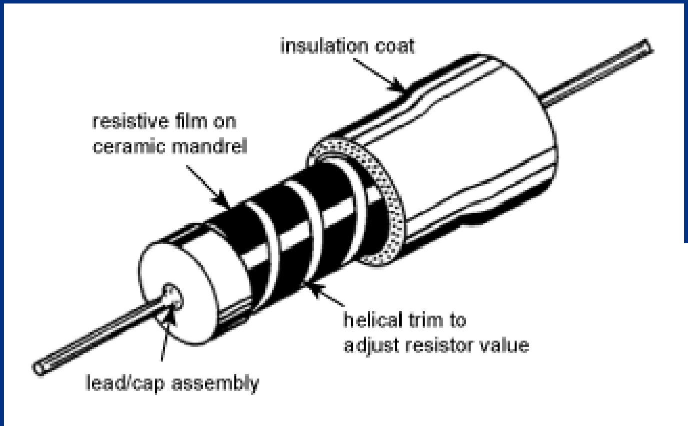
Wire wound resistors

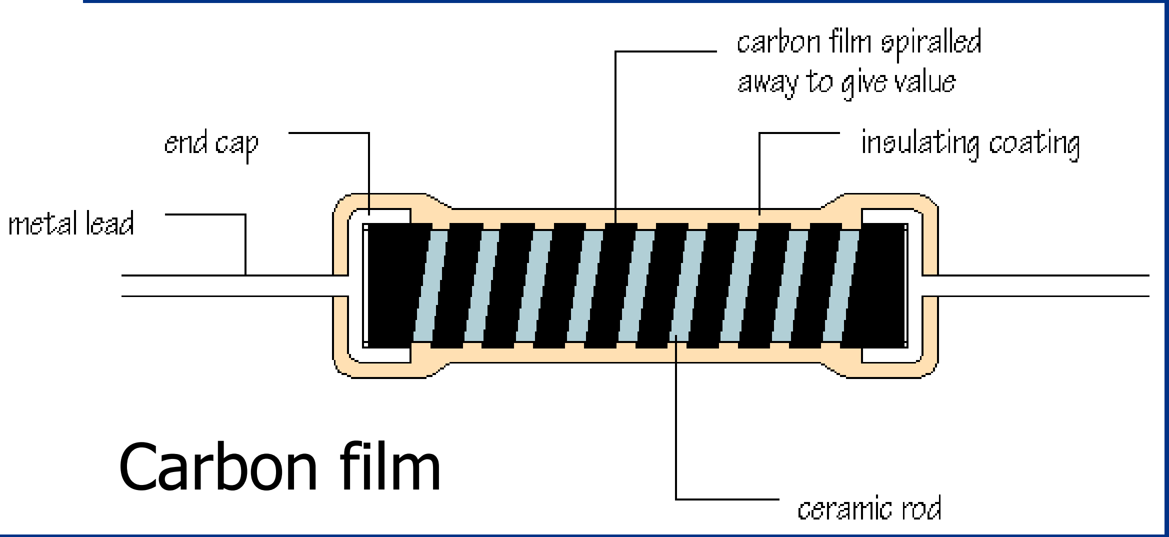




- **Wirewound** resistors are made by winding thin wire onto a ceramic rod.
- They can be made extremely accurately for use in multimeters, oscilloscopes and other measuring equipment.

Film resistors

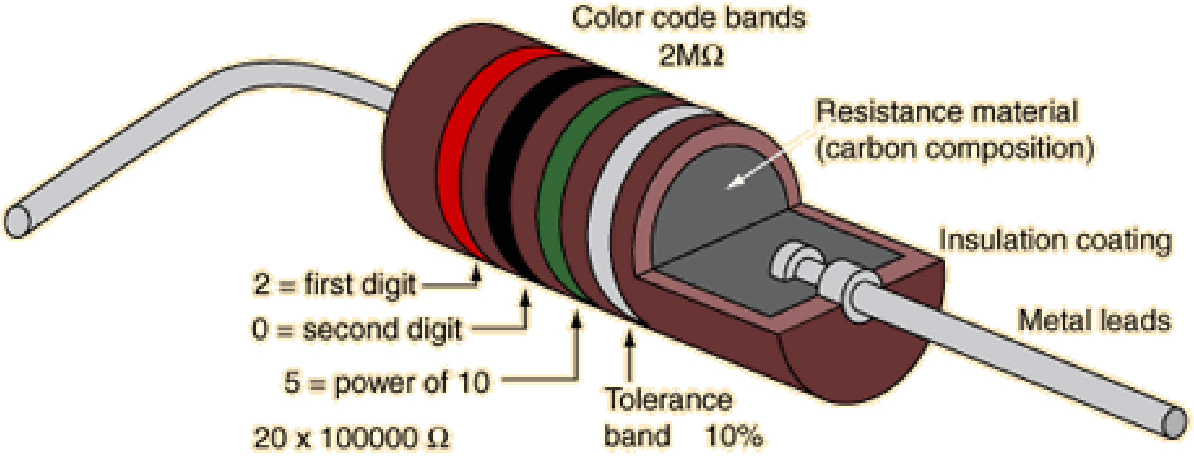




- A thin film of carbon is deposited onto a small ceramic rod.
  - The resistive coating is spiralled away in an automatic machine until the resistance between the two ends of the rod is as close as possible to the correct value.
  - Metal leads and end caps are added, the resistor is covered with an insulating coating and finally painted with coloured bands to indicate the resistor value.
- **Metal film** and **metal oxide** resistors are made in a similar way, but can be made more accurately to within ±2% or ±1% of their nominal value.

Through-hole mounted resistors

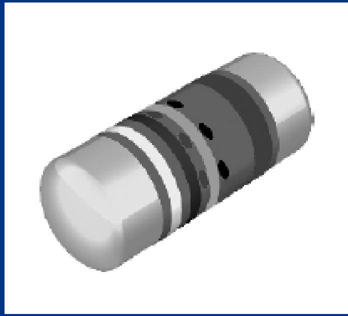
- Cylindrical body with two axial leads.

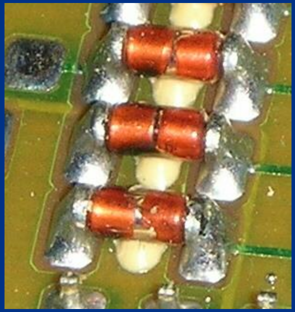


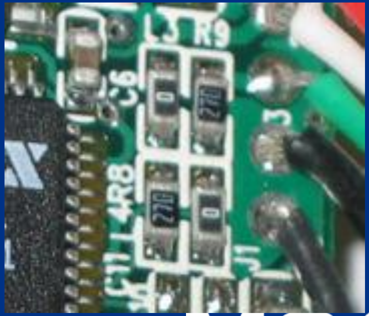
Surface mounted resistors

- ***Rectangular*** ceramic body with two solder terminals, often referred to as a ***chip resistors*** (***MELF***s are cylindrical)
    - MELF: Metal Electrode Leadless Face
- Ruthenium oxide ***thick film***, typ. 1-5 % tolerance
  Thin film technology using Ni-Cr or TaN
- ***Internal electrodes:*** most often silver (Ag)
- ***Terminals (end electrodes)***: Sn-Pb over Ni (barrier) or Ag-Pd, the latter also suitable for adhesive joining)

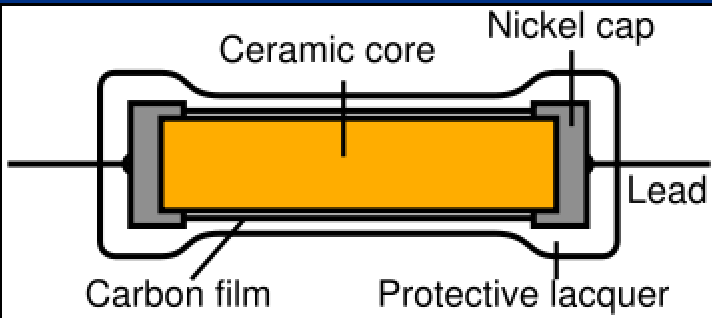
Size code	mm
1206	3.0 x 1.5
0805	2.0 x 1.25
0603	1.5 x 0.75
0402	1.0 x 0.5

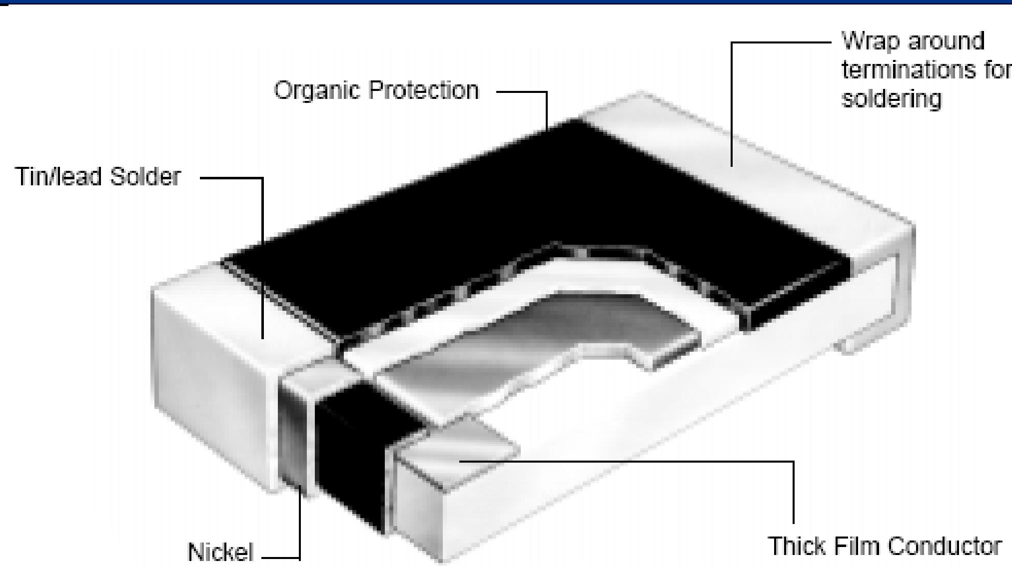


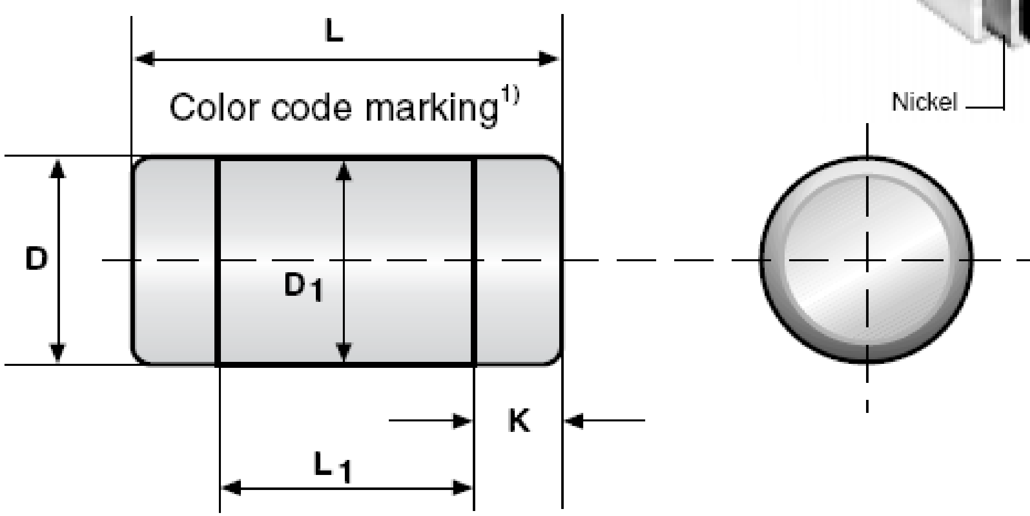


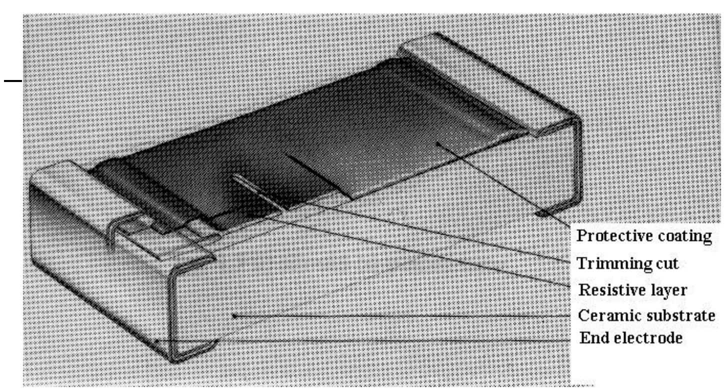


Resistors – Surface mounted









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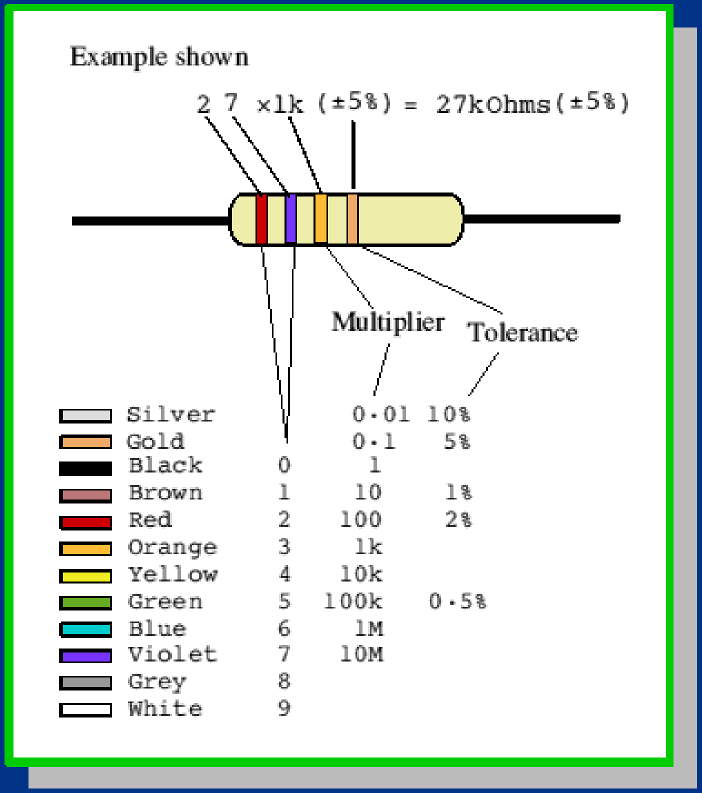
Color codes

•The resistance value and tolerance can be determined from the standard resistor color code.

Color	Digit	Multiplier	Tolerance
Black	0	1	
Brown	1	10	1%
Red	2	100	2%
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	
Blue	6	1,000,000	
Violet	7		
Grey	8		
White	9		
Gold		0.1	5%
Silver		0.01	10%



A 100R resistor with 5% tolerance may be anywhere between 95 and 105 ohms.

Standard values

- There are a number of different standards, commonly known as:
  - E12, E24, E48 and E96,
    - meaning that there are 12, 24, 48 or 96 individual values per decade (e.g. from 1k to 10k).
    - The most common are the E12 and E24 series
- The E12 and E24 series follow these sequences:

1	1.2	1.5	1.8	2.2	2.7	3.3	3.9	4.7	5.6	6.8	8.2	10

E12

1	1.1	1.2	1.3	1.5	1.6	1.8	2.0	2.2	2.4	2.7	3.0	3.3	3.6

3.9	4.3	4.7	5.1	5.6	6.2	6.8	7.5	8.2	9.1	10

E24

Screened-on resistors

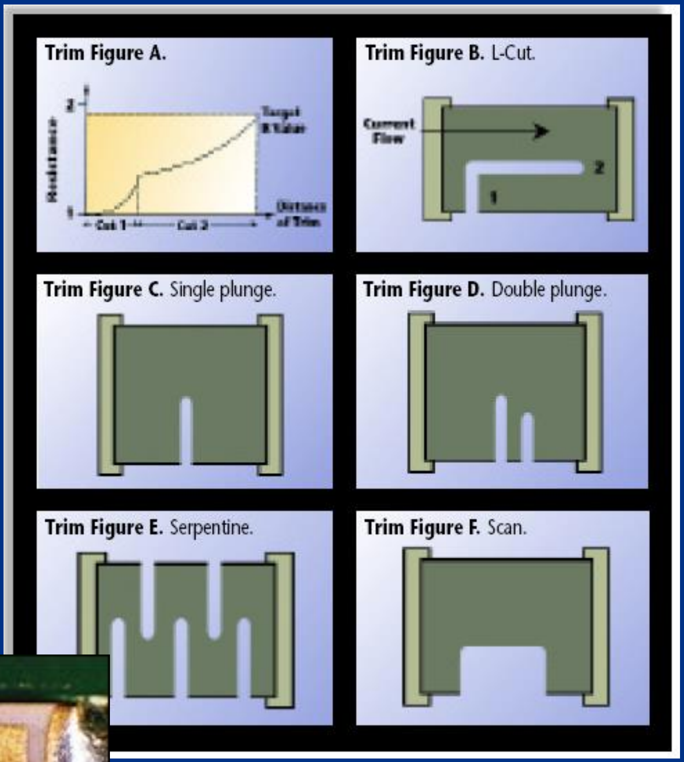
- In many cases the resistor is not a component added to the circuit, but a thick film creation applied as a paste to the circuit board between two conductive pads.
- These are screened-on resistors.
- Normally made to be adjustable by laser/abrasion manipulation of the path, such as the path gets elongated or narrowed in order to increase resistivity until target is achieved.

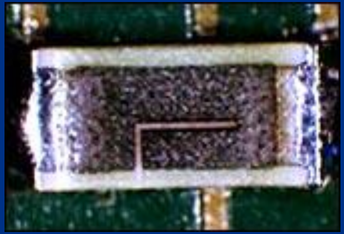
Resistance adjustment

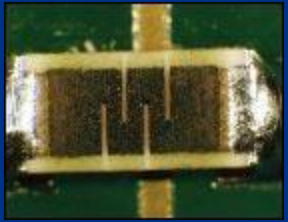
- The resistance adjustment of fired resistors forms an integral part of thick-film technology.
- This adjustment is done either by:
  - *Laser trimming* :
    - Evaporation of part of the material from the substrate by a high-power laser-beam.
  - *Air abrasive trimming* :
    - Stripping off a portion of the resistor material by a narrow jet of abrasive particles.

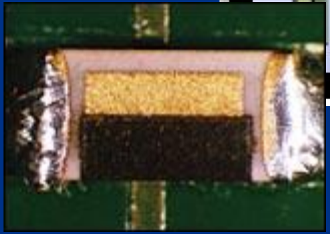
Laser trimming

- Laser trimming is a way of achieving precision adjustment of the attributes of an electronic circuit.
- A laser removes material from the appropriate component and thus adjusts its value.
  - Laser beam vaporising a cut into the resistor element.
  - Precise and fast process.
  - Low cost.
  - Clean process.
  - Stability depends critically on process.
  - Increased noise.




'L' cut into a thick film resistor


'Serpentine' cut


'Shave' cut

Abrasive trimming

- Sandblasted using a small nozzle.
- Very good long-term stability.
- Minimum equipment.
- Slow and “dirty” compared to Laser trimming.

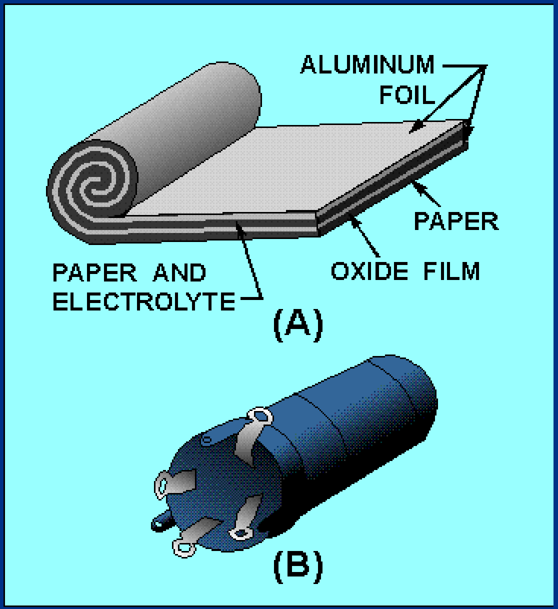
Capacitors

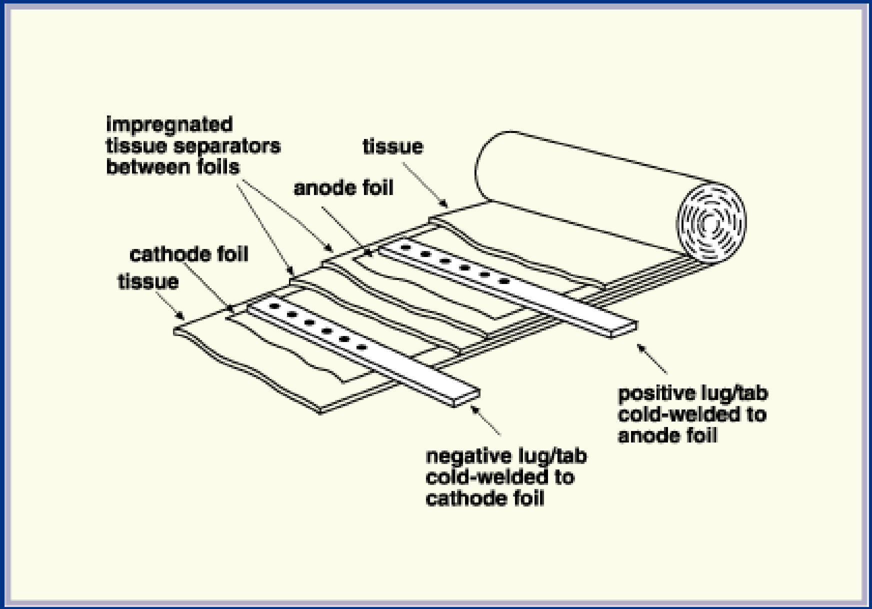
Main types of capacitors

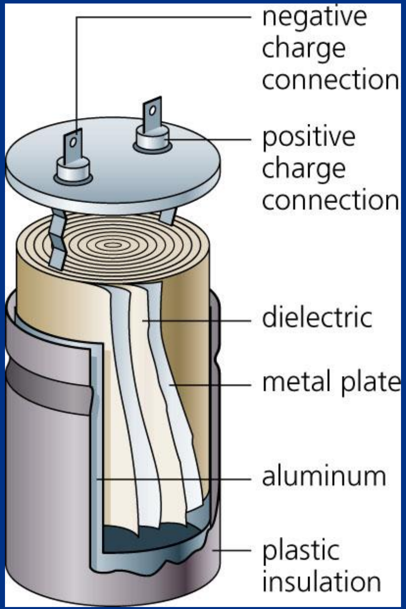
1. Aluminum electrolytic
2. Ceramic
3. Tantalum
4. Film

Electrolytic capacitors

- An ELECTROLYTIC CAPACITOR is used where a large amount of capacitance is required.
- An electrolytic capacitor contains an electrolyte.
- Two main types:
  - Wet electrolytic capacitor (the electrolyte is a liquid).
  - Dry electrolytic capacitor
    - consists essentially of two metal plates separated by the electrolyte.
- In most cases the capacitor is housed in a cylindrical Al container which acts as the negative terminal of the capacitor
- The positive terminal is a lug (or lugs) on the bottom end of the container.







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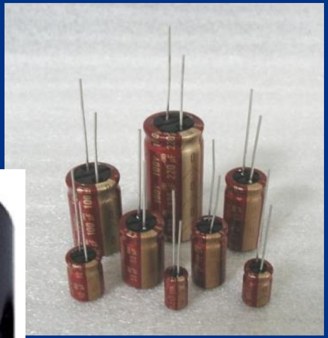
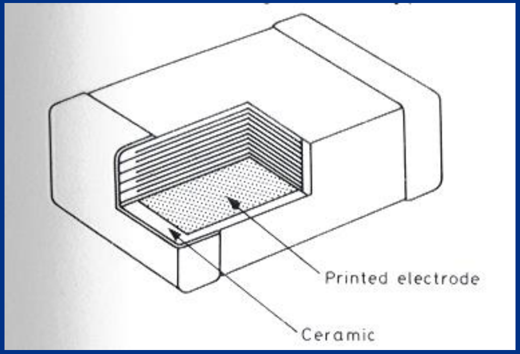
Electrolytic capacitors

- ***<u>Aluminum electrolytic:</u>***
  - Consists of two foils interleaved with an absorbent paper, and wound tightly into a cylinder.
  - The positive foil, or anode, is made from pure Al foil on the surface of which Al oxide dielectric has been formed electrolytically.
  - The foil has been etched to increase the effective surface area, and the area of the anode is typically 30–100 times larger than the plan area of the foil.
  - Polar (care must be taken when mounting)
    - Anode:
      - aluminium foil
    - Dielectric
      - Anodic oxidation of aluminium foil
    - Cathode: liquid electrolyte
  - High C values: 0.1 µF - 0.5 F ± 20 %

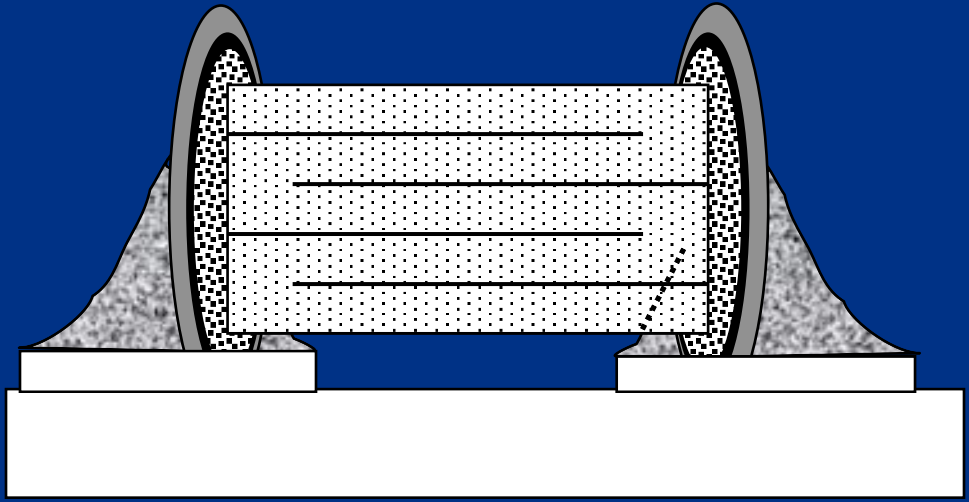


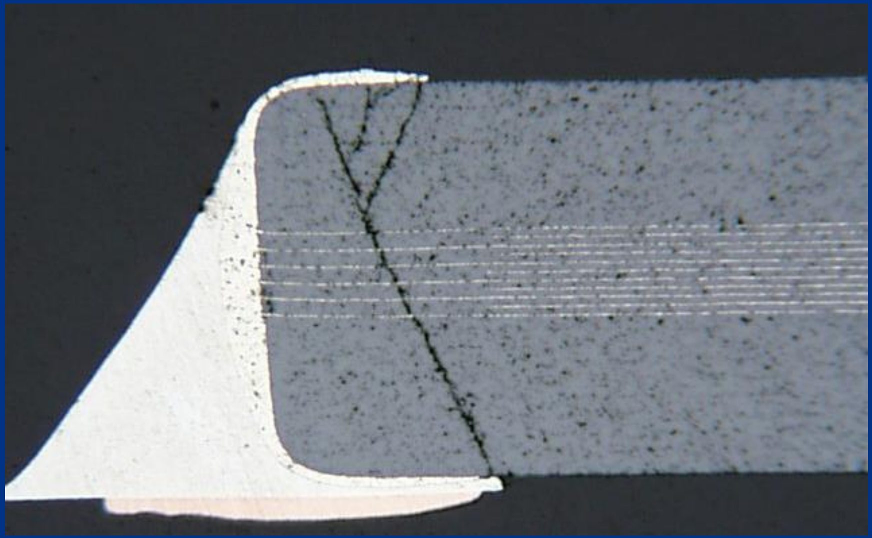
Ceramic capacitors

- ***Ceramic:***
  - Contains a ceramic dielectric.
  - Most dominant in both volumes and % of market share.
  - They are constructed in rolled or stacked form. The ceramic is typically a soft, flexible film before firing. The electrode material is screen printed onto the layers. These capacitors are very rugged, have low to mediate C.
  - 0,5 pF - 500 µF
  - Change from palladium to nickel, copper or silver - palladium as metallisation
    - Reduced cost
    - Needs reduced sintering temperature
  - Too high sintering temperature can lead to grain growth and evaporation of fluxes
  - Porosity



Cracking of ceramic capacitors





Common problem!

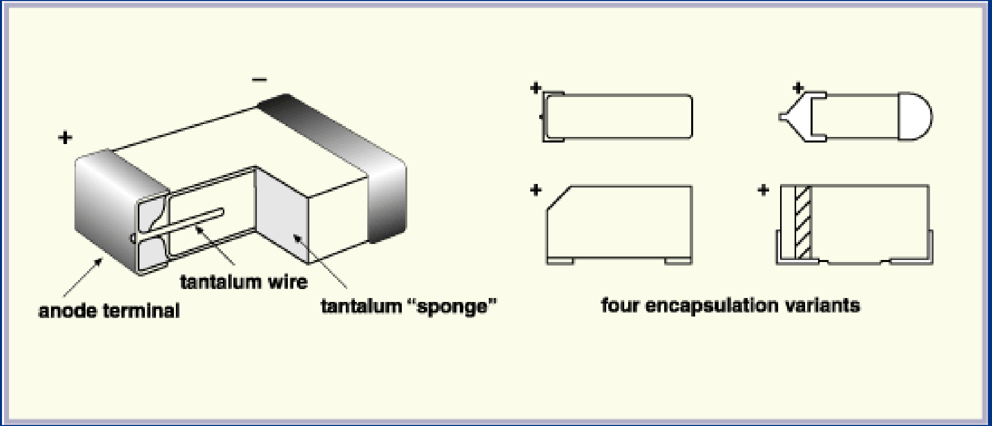
Tantalum capacitors

- ***Tantalum electrolytic:***
  - Similar to Al electrolyte capacitors.
    - Instead of rolled Al foil, the very large surface is obtained by using a very porous pressed pellet of Ta.
    - Ta oxide is the dielectric and the second electrode is wet (electrolyte paste)
  - 0.1-1000 µF

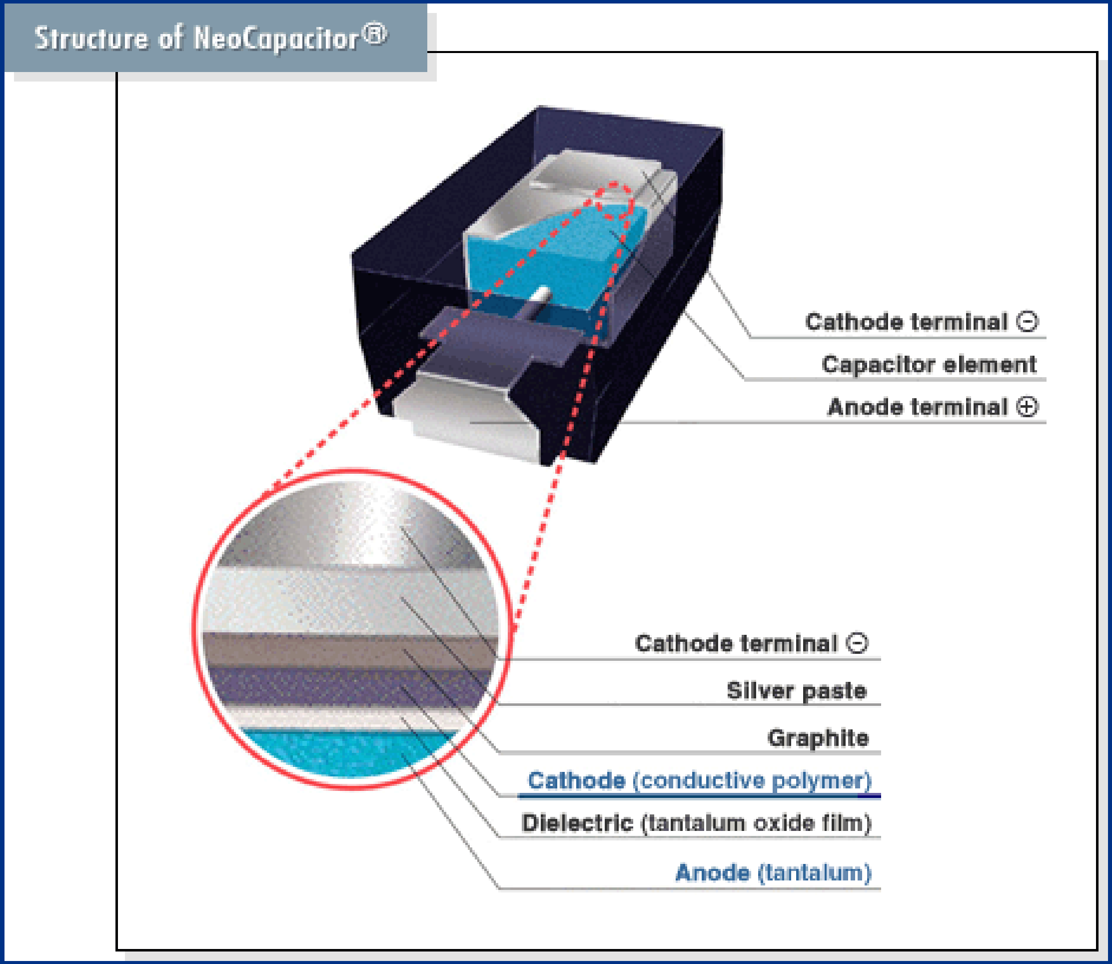
Very thin dielectric -> high capacitance

Tantalum capacitors

- **Solid tantalum**
  - Made by forming a rectangular parallelopiped from Ta powder around a Ta wire and sintering into a solid at more than 1,000°C in vacuum.
    - The 0.3-µm powder particles form a solid multiporous material with 1-µm pores.
    - The pores increase the slug's surface area, increasing the device's capacitance.
  - This multi-porous material is submerged in a liquid and a metal oxide layer is created on the surface.
    - This layer becomes an insulating layer /capacitor’s dielectric) and the multi-porous Ta assumes the role of the anode.
  - The cathode, which must cover all of the pores on the slug's surface, has traditionally been made from MnO_2 by soaking the slug in liquid manganese nitrate.



Tantalum capacitors



Film capacitors

- ***Film:***
  - Utilize an insulative film of plastic (polyester, polycarbonate, polypropylene, polystyrene) or fired ceramic.
  - Two main types:
    - ***Rolled foil***
      - Two conductive electrodes, either individual metal foils or as a thin metallization film, separated from each other by a plastic film are wound into a cylindrical shape.
    - ***Stacked layers***
  - 10 pF- 100 µF,
  - Low losses, bipolar, for decoupling and filter usage.

Film capacitors

- Rolled foil:
  - Al / plastic
  - Metallised ceramic
    - Dielectric 20 mm
    - Noble metal electrodes (Pd or Pt)

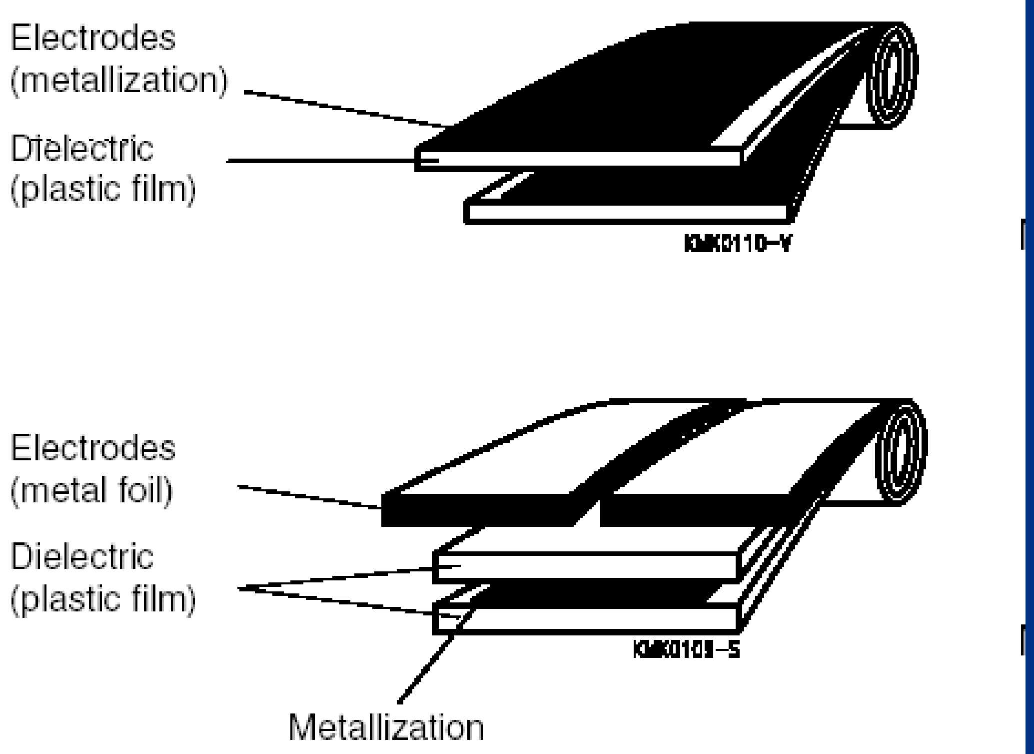


Fig. 3 Examples of typical foil and film arrangements

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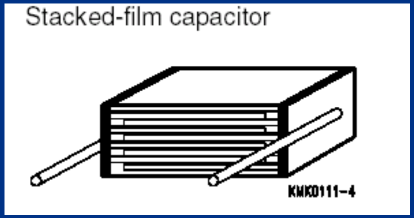
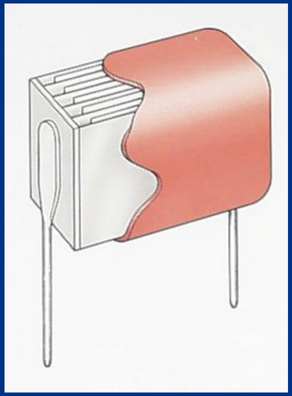
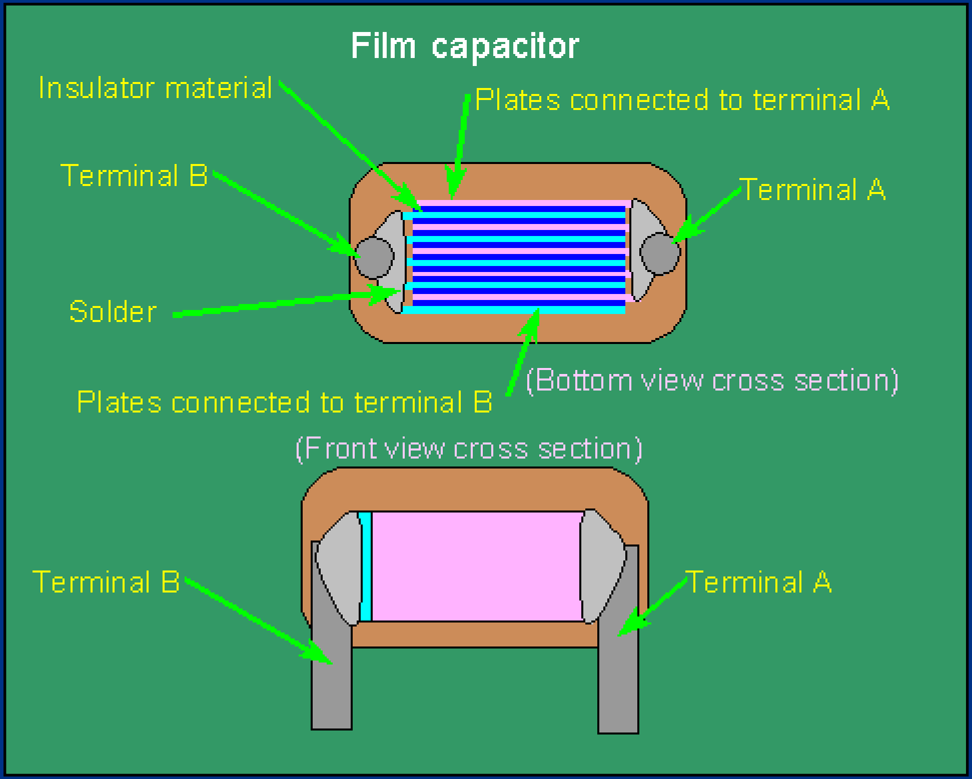
Film capacitor

- Stacked







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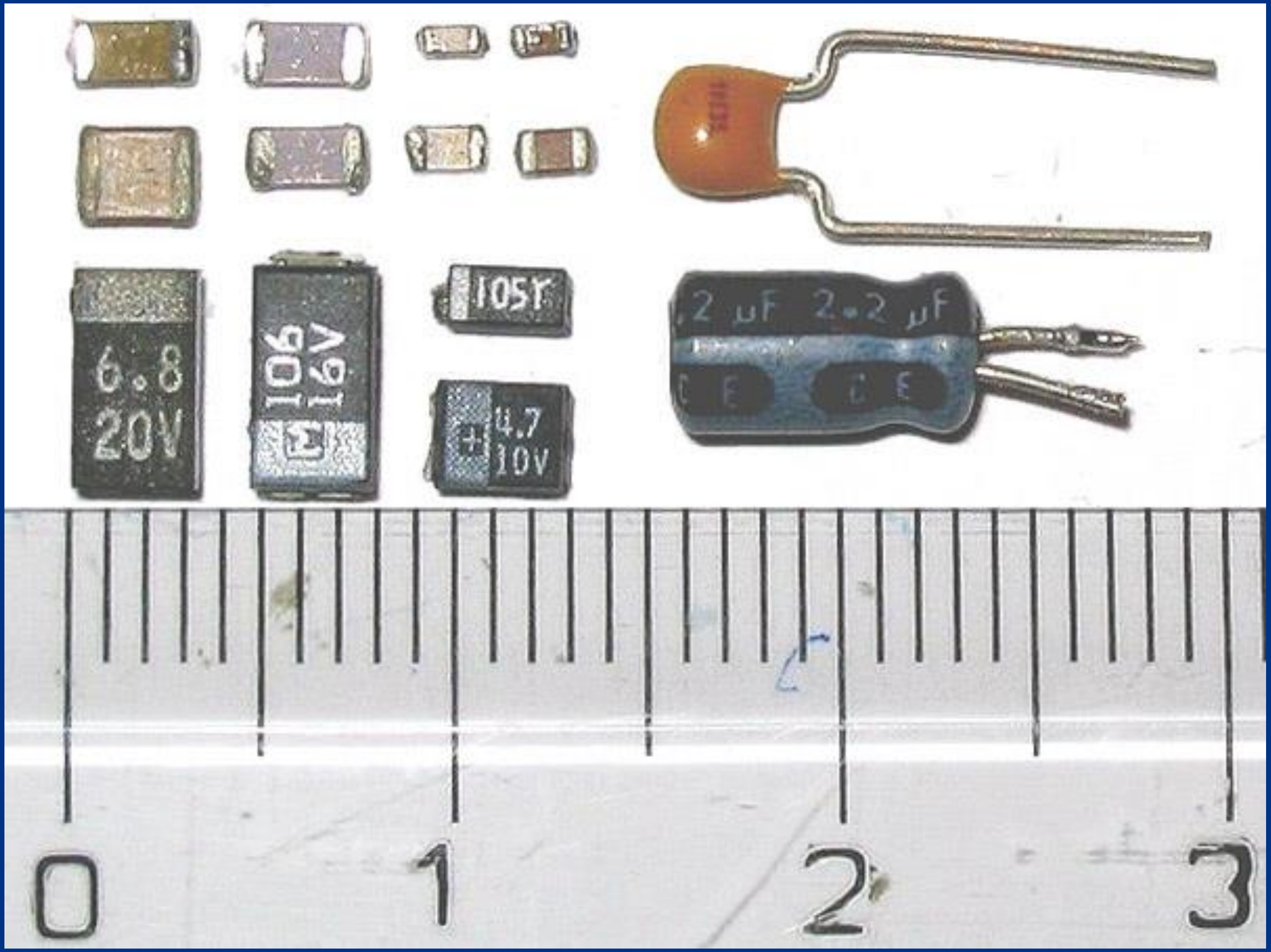
Coupling

- Capacitors pass AC but block DC signals (when charged up to the applied dc voltage), => they are often used to separate the AC and DC components of a signal.
- This method is known as *AC coupling* or "*capacitive coupling*".
- A large value of capacitance (whose value need not be accurately controlled, but whose reactance is small at the signal frequency) is employed.

Capacitor packages

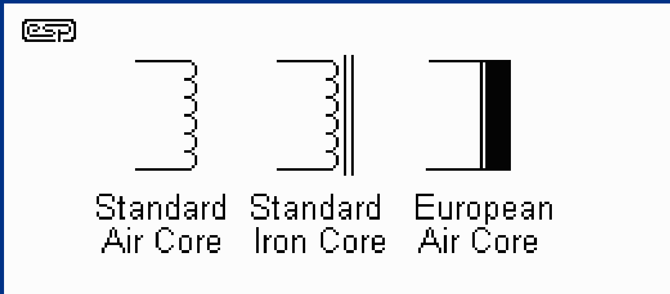


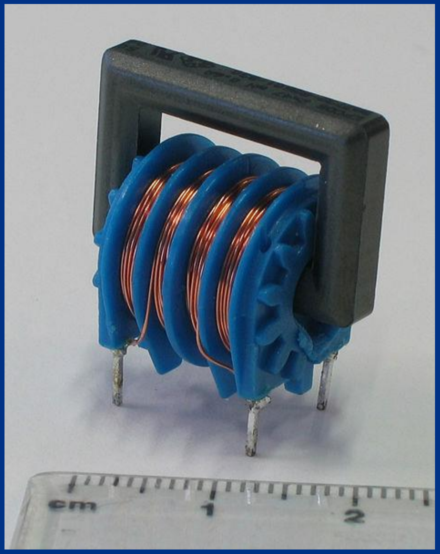
SMD: ceramic at top left; SMD tantalum at bottom left;
Through-hole: tantalum at top right; through-hole electrolytic at bottom right.
Major scale divisions are cm.

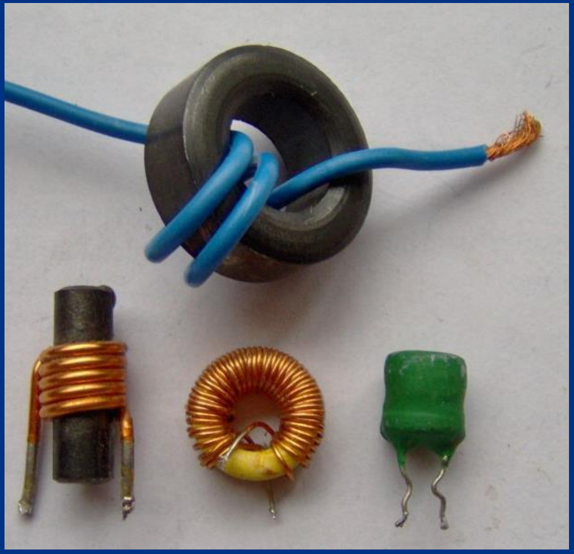
Inductors

Inductors

- An inductor is an impedance device comprising a coil, with or without core, for introducing inductance into an electric circuit.

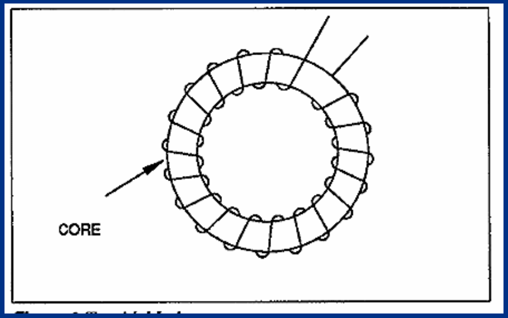






Inductors

- The magnetic material in the core increases the magnetic field inside the coil by the factor, μ_r.
  - An iron core with a relative permeability μ of 10^4 can significantly increase the magnetic field.
- Inductance materials:
  - The most common winding material is Cu.
- Core types:
  - Air (lowest inductance), various grades of steel or ferrite materials.
  - May be toroidal (shape like a ring) or can be in the traditional EI format.



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