EQUIPMENT DESIGN AND MATERIAL ENGINEERING

Materials, construction and reliability of electronic equipment

Materials

Materials used in electronics

- Construction materials – must possess proper mechanical properties, their electrical and chemical properties depend on demands;
  - Construction materials are mainly used for the main construction of electronic apparatus, chassis, element packages;
  - METALS
    - steel (the alloy of iron Fe and carbon C ≤ 2%),
    - copper (vacuum copper for anodes in vacuum tubes),
    - nickel and its alloys.
  - POLYMERS & ELASTOMERS
  - CERAMICS, COMPOSITES AND HYBRIDES

Materials

Materials used in electronics

- Conductive materials – must be characterised by good electrical conductivity;
  - They are used for electrical connections of devices, circuits and systems;
  - silver – the highest electrical conductivity, easily covered with oxides and sulphides;
  - copper, copper alloys – good electrical conductivity, lower price, good mechanical properties;
  - aluminium – good electrical conductivity, small density;
  - gold – mainly used for thin-film coatings, protection of conducting paths;

<table>
<thead>
<tr>
<th></th>
<th>Cu</th>
<th>Ag</th>
<th>Al</th>
<th>Au</th>
</tr>
</thead>
<tbody>
<tr>
<td>density [kg/m³]</td>
<td>8920</td>
<td>10490</td>
<td>2700</td>
<td>19300</td>
</tr>
<tr>
<td>electrical conductivity [S/m]</td>
<td>59,6·10⁶</td>
<td>63·10⁶</td>
<td>37,7·10⁶</td>
<td>45,2·10⁶</td>
</tr>
<tr>
<td>thermal conductivity [W/mK]</td>
<td>398</td>
<td>429</td>
<td>210</td>
<td>312</td>
</tr>
</tbody>
</table>

Materials

Materials used in electronics

- Resistive materials – used for heating elements, different types of resistors (industry and laboratory equipment, measurement applications), etc.
  - They should be characterised by:
    - appropriately high electrical resistivity;
    - small temperature coefficient of resistance;
    - long time stable resistances;
    - high resistivity to oxidation and chemical reactions;
    - high melting temperatures.
  - Resistive materials – (randomly pure metals) – increase of TCR with the increase of temperature;
    - low-alloy steel (Cr+Al+small additive of Cu) – 0,75 Ω·mm²/m
    - copper alloys (Cu <53-60%> + Ni <45-40%>), non-nickel alloys of iron and chromium
  - Resistive materials – decrease of TCR with the increase of temperature;
    - non-metal resistive materials
      - nickel-chromium alloys (nichrome)
Dielectric materials – usually used as insulating materials or capacitive materials.

**Dielectric should be characterised by:**
- Electrical parameters (high dielectric strength; high electric permittivity);
- Mechanical properties (high resistivity to mechanical treatment, bending, elongation, vibration etc.);
- Chemical properties (resistive to oxidation, acids and alkali);
- Technological properties (easy processing);

Materials used in electronics

### Dielectric materials – used in three states:
- Gaseous dielectrics
  - Noble gases – argon, neon (fluorescent lamps), helium;
  - Other gases – nitride (chemically neutral gas for technological processes; as an insulator in transformers), carbon dioxide;
- Liquid dielectrics – mineral oils; fluorocarbon liquids (e.g. FLUORINERT); wax;
- Solid dielectrics
  - Organic – mainly based on cellulose (e.g. paper)
  - Non-organic – ceramic materials; glass; mica

Materials used in electronics

### Semiconductors – the most popular are:
- Elements – silicon (Si); germanium (Ge);
- Compounds – gallium arsenide (GaAs); indium phosphide (InP); gallium nitride (GaN); silicon carbide (SiC);
- Alloys – silicon-germanium (SiGe);
- Polymers and other organic compounds

<table>
<thead>
<tr>
<th>Material</th>
<th>Density [kg/m³]</th>
<th>Energy band gap [eV]</th>
<th>Electron mobility [cm²/Vs]</th>
<th>Hole mobility [cm²/Vs]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>2330</td>
<td>1.12</td>
<td>1350</td>
<td>450</td>
</tr>
<tr>
<td>Ge</td>
<td>5320</td>
<td>0.66</td>
<td>3900</td>
<td>1900</td>
</tr>
<tr>
<td>GaAs</td>
<td>5220</td>
<td>1.43</td>
<td>8500</td>
<td>330</td>
</tr>
<tr>
<td>SiC</td>
<td>3210</td>
<td>2.2-3.2</td>
<td>500-1000</td>
<td>40-120</td>
</tr>
</tbody>
</table>

**The main goal of protective coatings is to protect the covered surface. The coatings should be characterised by:**
- Good adhesion to the substrate;
- High wear and scratch resistivity;
- High corrosion resistance.

**Layer thickness:** 0.2 - 25 µm

**Materials used for protective coatings:** nickel, chromium, copper, silver, tin, zinc, lead, cadmium, aluminium and gold.

**Coating techniques:**
- Electrochemical,
- Chemical,
- Vapour deposition.

Technologies

### Thick and thin film technologies
- Criteria to distinguish thick and thin film technologies
  - Layer thickness ≥1µm (not a very crucial criterion);
  - Type of technology.
- Thin film technologies are all the production techniques that use advanced apparatus operating in clean room facilities. These technologies allow to produce and to form layers of the thickness from fraction of nanometers up to several micrometers (accuracy of arrangement at the atomic level).
- Basic thin film techniques:
  - Deposition;
  - Oxidation;
  - Etching.
Thick film technologies belongs to the standard deposition techniques that allow to produce the layers of several micrometers (standard range 2 – 35 μm).

Thick film technologies do not require spaces with controlled level of contamination. Very popular in industry due to low cost of materials, technological equipment and not demanding conditions.

Layers created with the aid of thick-film technology are usually characterised by lower purity, poorer arrangement in comparison to films obtained with thin-film techniques.

The basic material in this technology is the paste composed of:
- active phase – metal powders and metal oxide powders determining the electrical properties of the layers;
- binding phase – usually responsible for creation of permanent connection of active phase and the substrate;
- organic components – epoxies + solvents (responsible for printing properties)

Types of pastes:
- Conducting pastes;
- Resistive pastes;
- Dielectric pastes

The first stage of electronic equipment construction process is to specify the preliminary technical terms:
- Functional requirements
  - idea (what should be created and how should it operate?)
  - destination (who and how will operate it?)
  - technical parameters
- Environmental threats
  - durability/resistance
- Measurement methodology (according to national or international standards)
- Reliability conditions
- Preliminary economic analysis
  - Manufacturing costs
  - Usage costs
  - Maintenance costs

The second stage of electronic equipment construction process is to elaborate the preliminary design:
- General concept of the device
- Design and calculation of electronic circuits
- Element selection (data sheet) – circuit sensitivity analysis
- Packaging/housing
  - type/size/construction
  - circuit locations
  - cooling
- Manufacturing of equipment model
- Testing (the model must obey all the requirements defined in the preliminary technical terms)

The third stage of electronic equipment construction process is to elaborate the technical project:
- Elaboration of detailed technical documentation
- Elaboration of technological processes
- Manufacturing of prototype equipment
- Testing of prototype equipment according to technical specifications
Properties of electronic equipment

Properties of electronic equipment that decide about its use can be divided into two groups:

- Functional – the product application
- Operational – the ability of the product to maintain its functional properties during its normal operation

All electronic equipment operate in the environment!

Environmental conditions influences electronic devices, circuits and systems.

**THERE IS NO POSSIBILITY to completely eliminate the activity of environmental components!!!**

Environmental threats

Types of environmental threats:

- **climate** – natural environmental conditions such as: temperature, humidity, pressure,
- **atmospheric corrosion** – usually resulting from industrial pollution in the form of gases, liquids (mist), solids (dust),
- **radiation** – infrared radiation, ultraviolet radiation, ionisation, etc.,
- **biotic components** – living organisms and their development: micro-organisms (bacteria, mould, fungus...), macrobiotic factors (animals, insects, plants),
- **mechanical factors** – static and dynamic forces (impacts, shocks, vibrations),
- **human factors** – resulting from presence and activity of human beings.

Reliability

**Reliability vs. failure rate**

Reliability is a parameter of electronic equipment (device, circuit, system) that defines a probability that the element will perform its required function for a specified interval under stated conditions.

Reliability is described by the formula:

\[ R(t) = \lim_{N \to \infty} \frac{N - n(t)}{N} \]

where: \( N \) – number of used devices; \( n(t) \) – number of faulty products in the period of \( t \)

FOR HIGH VALUES OF \( N \)

\[ R(t) \approx 1 - \lambda t \]

where: \( \lambda \) - failure rate [1/h]; and \( t \) – time [s].

In most of the cases the failure rate does not depend on usage time; so \( \lambda(t) = \text{const.} \)

Moreover, if \( \lambda t \leq 0,1 \) the above formula can be simplified to:

\[ R(t) = 1 - \lambda t \]

**Failure rate**

Typical values of failure rates for different electronic elements:

<table>
<thead>
<tr>
<th>Element</th>
<th>( \lambda \times 10^{-6} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soldered connections</td>
<td>0,01</td>
</tr>
<tr>
<td>Wrapped connections</td>
<td>0,001</td>
</tr>
<tr>
<td>Capacitor</td>
<td>0,1</td>
</tr>
<tr>
<td>Standard resistor</td>
<td>0,05</td>
</tr>
<tr>
<td>Printed resistor</td>
<td>0,02</td>
</tr>
<tr>
<td>Ge transistor</td>
<td>0,5</td>
</tr>
<tr>
<td>Si transistor</td>
<td>0,08</td>
</tr>
<tr>
<td>Analog microchip</td>
<td>0,3</td>
</tr>
<tr>
<td>Digital microchip</td>
<td>0,1</td>
</tr>
</tbody>
</table>


Mean time to failure

Failure rate as the frequency with which a system or a component fails, can be used to evaluate parameter MTTF (mean time to failure):

\[ MTTF = \frac{1}{\lambda} \]

Under the assumption \( \lambda t \leq 0,1 \) the MTTF parameter can be expressed as:

\[ MTTF = \frac{1}{1 - R(t)} \]
Reliability

Reliability of basic structures

Series structure – proper operation of the whole system is determined by proper operation of every component. The reliability of the system of k-elements in series configuration is described by the formula:

\[ R_S(t) = \prod_{i=1}^{k} r_i(t) = \prod_{i=1}^{k} \exp(-\lambda_i t) = \exp\left(-\sum_{i=1}^{k} \lambda_i t\right) \]

where: \( r_i(t) \), \( r_S(t) \) – reliabilities of the components; \( \lambda_i \), \( \lambda_S \) – failure rate of the components.

For three elements:

\[ R_3(t) = r_1(t) \cdot r_2(t) \cdot r_3(t) = \exp(-\lambda_1 - \lambda_2 - \lambda_3) t = \exp(-\lambda_S t) \]

\( \lambda_S = \lambda_1 + \lambda_2 + \lambda_3 \)

Reliability

Reliability of basic structures

Parallel structure – a few elements fulfill the same role in circuits. Hence, the whole structure is working properly if ANY of the elements is operating properly:

\[ R_P(t) = 1 - \left[ (1 - r_1(t)) \cdot (1 - r_2(t)) \cdot \ldots \cdot (1 - r_k(t)) \right] = 1 - \left[ 1 - \exp(-\lambda_S t) \right]^k \]

where: \( r_i(t) \), \( r_P(t) \) – reliabilities of the components; \( \lambda_i \), \( \lambda_P \) – failure rate of the components

For three elements:

\[ R_3(t) = 1 - [1 - r_1(t)][1 - r_2(t)][1 - r_3(t)] \]

Reliability

Example 1

The 4-bit pulse counter consists of 4 integrated circuits (each with 0.2 \( \times \) 10^-5 l/h failure rate) and 20 welded connections with 0.01 \( \times \) 10^-5 l/h failure rate. Calculate reliability of the system for 1 year of continuous operation.

Example 2

Calculate the reliability of supply system composed of a main power supply with 10^-1 l/h failure rate and a battery supply with 10^-2 l/h failure rate. Please, give the result for 50h of continuous operation.

Reliability

Failure rate

• Variation of failure rate in time

\[ \lambda(t) = \lambda_0 \exp(-W t) \]

where:

\( \lambda_0 \) – failure rate at \( t = 0 \)

\( W \) – activation energy of degradation process

\( k \) – Boltzmann’s constant

\( T \) – absolute temperature

\( \lambda_n \) – parameter of degradation process

Reliability

Failure rate – activation energy of degradation processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Activation Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium penetration into structure</td>
<td>1,3 eV</td>
</tr>
<tr>
<td>Contamination radiation to the surface</td>
<td>1,1 eV</td>
</tr>
<tr>
<td>Aluminium corrosion</td>
<td>0,6 eV</td>
</tr>
<tr>
<td>Inter-metallic compound creation of gold and aluminium</td>
<td>0,7 eV</td>
</tr>
<tr>
<td>Aluminium electroreduction</td>
<td>0,6 eV</td>
</tr>
<tr>
<td>Volume friction effects of silicon and oxides</td>
<td>0,3 eV</td>
</tr>
</tbody>
</table>

Failure rate:

• For \( W_0 = 1,3 eV \)

\[ \frac{1400}{1000} \times 10^6 \]

• For \( W_0 = 0,3 eV \)

\[ \frac{1400}{1000} \times 10^2 \]
Reliability

Design solutions leading towards higher final reliabilities:
- simplification (development only for real improvement of the device functionality),
- implementation of typical and tested circuits,
- usage of elements with big tolerance for parameters’ fluctuations,
- reduction of the elements requiring high - stability voltage supply systems
- implementation of diagnostic circuits
- implementation of common, mass-production elements and technologies
- minimisation of control and adjustment elements number,
- minimisation of multiple-function circuits.

Reliability

Proper protection at the transport and storage stage that leads towards higher final reliability:
- packaging with gravity overloading protection (soft materials, additional foams,...),
- proper temperature and humidity in storage buildings,
- packaging systems resistive to aggressive surrounding influence,
- anticorrosive protection (oils, lubricants, foils),
- inhibitors - humidity absorbents,
- microclimates (additional encapsulation with protective atmospheres).

EQUIPMENT DESIGN AND MATERIAL ENGINEERING

Printed Circuit Boards

Mounting levels

Due to the technological and utilisation aspects, the electronic equipment must be divided into smaller subassemblies called modules. Each module should:
- contain electronic circuit with defined functionality
- be manufactured with the aid of one technology,
- be normalised (dimensions, geometry) to simplify its service and maintenance.

<table>
<thead>
<tr>
<th>MODULE</th>
<th>CONNECTIONS</th>
<th>MOUNTING LEVELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>semiconductor structure</td>
<td>wires; conducting glue; FC</td>
<td>I</td>
</tr>
<tr>
<td>integrated circuits</td>
<td>soldering; conducting glue</td>
<td>II</td>
</tr>
<tr>
<td>basic module; PCB</td>
<td>connectors; electric cables</td>
<td>III</td>
</tr>
<tr>
<td>blocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>systems</td>
<td>cables; wires</td>
<td>IV</td>
</tr>
</tbody>
</table>

Printed circuit board

Printed Circuit Board (PCB) is a board made of non-conductive substrate with mosaic of conductive paths and pads manufactured on its surface dedicated for inter-component connection realisation and assembly of electronic circuits;
- PCB provides:
  ✓ physical structure for mounting and holding electronic components;
  ✓ electrical interconnection between components.

Main acronyms

PCB – Printed Circuit Board
SMT – Surface Mount Technology
SMD – Surface Mount Device (a device that is suitable for SMT)
THT – Through Hole Technology
THD – Through Hole Device (a device that is suitable for THD)
Printed circuit board

ELEMENTS OF CONDUCTIVE MOSAIC
- Soldering pads,
- Tracks,
- Vias,
- Anti-Magnetic shields,
- Ground pads,
- Contacting pads of edge connectors,
- Test pads,
- Optical reference marks.

Printed circuit board

ADVANTAGES:
- Small manufacturing costs (independent on circuit type and its complexity),
- High repetitiveness of electrical and mechanical properties,
- Low assembling costs (automation of component placing and soldering technologies),
- Small dimensions and low weight of final product,
- High reliability (higher quality and repeatability),
- Short control and measurement procedures,
- Simple protection against environmental exposures.

DISADVANTAGES:
- Difficulties in modifications of the construction,
- Higher vibration vulnerability,
- Difficulties in heat transfer processes.

Printed circuit board

TYPES OF PCBs:
According to substrate type:
- Rigid
- Ceramic
- Specials
- Flexible
- Rigid-flex

According to construction type:
- Single-sided
- Double-sided
- Multilayer

According to patterning technology:
- Subtractive method
- Additive method
- Semi-additive method

Printed circuit board

MANUFACTURING:

Rigid substrates

Printed circuit board

Rigid substrates

SUBSTRATE THICKNESS:
- One-layer board: 0.8 ÷ 6mm,
- Multi-layer board: 0.05 < 0.75mm / layer,

COPPER FOIL THICKNESS:
- 5μm; 9μm; 17.5μm; 35μm; 70μm; 105μm

Printed circuit board

POPULAR LAMINATES:

<table>
<thead>
<tr>
<th>Resin</th>
<th>Filler</th>
<th>Filler form</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pencil</td>
<td>paper</td>
<td>sheet</td>
<td>PR-2; X; XP; XG; ...</td>
</tr>
<tr>
<td></td>
<td>cotton</td>
<td>fabric</td>
<td>C, CE; L; LE</td>
</tr>
<tr>
<td></td>
<td>glass</td>
<td>fabric</td>
<td>G-2</td>
</tr>
<tr>
<td></td>
<td>nylon</td>
<td>fabric</td>
<td>G-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R-1</td>
</tr>
<tr>
<td>Amino</td>
<td>glass</td>
<td>fabric</td>
<td>ES-1; ES-3; G-5; G-9</td>
</tr>
<tr>
<td>Epoxy</td>
<td>paper</td>
<td>sheet</td>
<td>PR-3</td>
</tr>
<tr>
<td></td>
<td>glass</td>
<td>fabric</td>
<td>G-10; G-15; PR-6; PR-8</td>
</tr>
<tr>
<td>Alum</td>
<td>glass</td>
<td>metal</td>
<td>GPO-1; GPO-2</td>
</tr>
<tr>
<td>Silicon</td>
<td>glass</td>
<td>fabric</td>
<td></td>
</tr>
</tbody>
</table>
### Rigid substrates

#### PARAMETERS OF POPULAR LAMINATES:

<table>
<thead>
<tr>
<th>Parameter type</th>
<th>UNIT</th>
<th>FR-2</th>
<th>FR-4</th>
<th>GPO-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>density</td>
<td>g/cm³</td>
<td>3,7</td>
<td>3,3</td>
<td>3,9</td>
</tr>
<tr>
<td>TCE: x, y</td>
<td>ppm/K</td>
<td>7,6</td>
<td>4,9</td>
<td>8,1</td>
</tr>
<tr>
<td>thermal conductivity</td>
<td>W/mK</td>
<td>25-37</td>
<td>270</td>
<td>273</td>
</tr>
<tr>
<td>dielectric const.</td>
<td>(MHz)</td>
<td>9 - 10</td>
<td>10</td>
<td>6,6</td>
</tr>
<tr>
<td>dielectric strength</td>
<td>W/mm²</td>
<td>8 - 10</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>flexural strength</td>
<td>MPa</td>
<td>32 - 49</td>
<td>-</td>
<td>19</td>
</tr>
<tr>
<td>max operating temp.</td>
<td>°C</td>
<td>1700</td>
<td>700</td>
<td>1200</td>
</tr>
<tr>
<td>hygroscopy</td>
<td>%</td>
<td>0,8</td>
<td>0,35</td>
<td>1,0</td>
</tr>
</tbody>
</table>

### Flexible substrates

#### PROPERTIES OF STANDARD FLEXIBLE SUBSTRATES:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Polyimide</th>
<th>Polyester</th>
<th>Aramid</th>
<th>Epoxyide</th>
</tr>
</thead>
<tbody>
<tr>
<td>flexural strength (MPa)</td>
<td>175-210</td>
<td>154-196</td>
<td>77</td>
<td>245-260</td>
</tr>
<tr>
<td>max elongation (%)</td>
<td>60-80</td>
<td>65-165</td>
<td>7-10</td>
<td>3-5</td>
</tr>
<tr>
<td>max temperature (°C)</td>
<td>200-300</td>
<td>180-200</td>
<td>55-200</td>
<td>155-165</td>
</tr>
<tr>
<td>glass point (°C)</td>
<td>220-260</td>
<td>90-110</td>
<td>90-165</td>
<td>120-150</td>
</tr>
<tr>
<td>TCE (ppm/°C)</td>
<td>20</td>
<td>27</td>
<td>22</td>
<td>10-12</td>
</tr>
<tr>
<td>permeability</td>
<td>3,4</td>
<td>3,0</td>
<td>2,1</td>
<td>4,5-5,3</td>
</tr>
<tr>
<td>dielectric strength (kV/mm)</td>
<td>144</td>
<td>136</td>
<td>20</td>
<td>9,6</td>
</tr>
<tr>
<td>hygroscopy (%)</td>
<td>2,9</td>
<td>0,3</td>
<td>8-9</td>
<td>0,05-3</td>
</tr>
</tbody>
</table>

### Ceramic substrates

#### PROPERTIES OF STANDARD CERAMIC SUBSTRATES:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Al₂O₃</th>
<th>AlN</th>
<th>BeO</th>
</tr>
</thead>
<tbody>
<tr>
<td>density</td>
<td>g/cm³</td>
<td>3,7</td>
<td>3,3</td>
<td>3,9</td>
</tr>
<tr>
<td>TCE: 20-60°C</td>
<td>ppm/K</td>
<td>7,6</td>
<td>4,9</td>
<td>8,1</td>
</tr>
<tr>
<td>TCE: 20-100°C</td>
<td>ppm/K</td>
<td>8,2</td>
<td>6,6</td>
<td>9,4</td>
</tr>
<tr>
<td>thermal conductivity</td>
<td>W/mK</td>
<td>25-37</td>
<td>170-215</td>
<td>273</td>
</tr>
<tr>
<td>dielectric const. (MHz)</td>
<td>-</td>
<td>9 - 10</td>
<td>10</td>
<td>6,6</td>
</tr>
<tr>
<td>dielectric strength</td>
<td>W/mm²</td>
<td>8 - 10</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>flexural strength</td>
<td>kPa</td>
<td>32 - 49</td>
<td>-</td>
<td>19</td>
</tr>
<tr>
<td>max operating temp.</td>
<td>°C</td>
<td>1700</td>
<td>700</td>
<td>1200</td>
</tr>
<tr>
<td>hygroscopy</td>
<td>%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Rigid substrates

#### ADVANTAGES OF FR-4:
- price adequate to its electrical and mechanical properties;
- perfect for mass production;
- flame resistant;

#### DISADVANTAGES FR-4:
- difficult for hole drilling;
- poor dimension stability;
- low glass point of the resin (120 – 160°C);
- mismatch of thermal coefficients of expansion of laminate and the elements;
- necessity of waste utilisation.
PCB manufacturing

Methods of copper foil manufacturing:
- Rolled annealing (99.9% Cu) – mainly for flexible substrates
  - good horizontal grain structure, flexible solution
  - good solderability, poor adhesion and ductility
- Electroplating (electrolytic copper foil of 99.5% Cu) – mainly for rigid substrates
  - bond strength, better photo-resist adhesion
  - mainly for rigid solutions
- Vapour deposition

Subtractive method:
- The initial material is copper clad laminate
- Types:
  - Chemical etching,
  - Micromachining (milling),
  - Laser micromachining.

PCB manufacturing

Additive methods:
- Additive with photoresist,
  - hole drilling
  - reverse pattern plating resist application
  - copper electroless plating up to the required thickness,
  - photoresist removal.
- Photo-additive,
  - hole drilling,
  - resin activation and seeding in the areas of conducting mosaic,
  - copper electroless plating up to a required thickness.

PCB manufacturing

Subtractive method - limitations:
- track width is limited to 0.2 mm,
- underetching of tracks can be observed

PCB manufacturing

DCB (Direct Copper Bonding) technology:
- The most common ceramic is Al₂O₃ (96%),
- AlN is characterised by better thermal parameters
- Dimension limitations due to the deformations of the substrates during annealing

Subtractive method: Subtractive method & limitations:
- The board is exposed to...
**Assembly types**

- **Through hole assembly**
- **Surface mount assembly**
- **Mixed Assembly – type I**
- **Mixed Assembly – type II**

**Selection of elements**

Main criteria for package selection:
- Element type,
- Assembly type (SMT vs. THT),
- Power dissipation,
- Environmental conditions,
- Price and package availability.

**Elements for through-hole assembly**

Through-Hole Components are those components which have leads that can be inserted through mounting holes in the circuit boards. One can distinguish:

According to number of leads:
- Two-lead elements,
- Multi-lead elements,

According to lead configuration:
- Axial leads,
- Radial leads.

**Elements for through-hole assembly**

Axial components:
- Usually with cylindrical shape.
- Leads are extending from each of two sides of the component package.
- Leads must be bent for insertion through the hole. The distance between soldering points can vary.
- Leads are usually made of copper wires with diameters 0.38 to 0.81 mm covered with special coatings.
- Resistors, capacitors, diodes, some inductors.

Radial components:
- Different shape of packages: disks, rectangular, tubular.
- Leads emanate from one side of the component.
- Inter-lead spacing (lead pitch) usually equals to 2.54 mm = 100 mils.
- Some resistances, most of the capacitors and optoelectronic elements e.g. LED.

Multi-lead components:
- Active elements: transistors, integrated circuits.
- Rectangular or tubular shapes dominate.
- Tubular packages: usually metal packages (TO5, TO18, TO98) sometimes plastic packages (TO92).
- Integrated circuits in tubular packages - number of leads = 4, 6, 8, 10, 12 or 14.
- Rectangular packages: moulded plastic (consumer solutions) or ceramic (professional equipment).
Elements for through-hole assembly

- Integrated circuits:
  - Circuits of small-scale and medium-scale integration: DIL or DIP (Dual-in-line Package) – rectangular package with two parallel rows of leads (pins); SII or SIP (Single In-line Package) – leads in a single row.
  - Packages usually referred as eg, DIP14.
  - 1st pin is marked on the package and others are numbered counter-clockwise.
  - Mismatch of TCs reduces application of SIP and DIP to VLSI (max 64 leads).
  - VLSI array packages: PGA (Pin Grid Array) – pins are arranged in rectangular array on one side of the package.

- Sockets, connectors:
  - Multi-lead solutions;
  - Standardisation;
  - Easy replacement of the elements.

Elements for surface mount assembly

- Ceramic capacitors:
  - Flat solution composed of several metal clad ceramic layers (even up to 50 layers);
  - Solutions not resistive to heat treatment;

- Polarised components:
  - Diodes, electrolyte capacitors, tantalum capacitors;
  - Two terminals;
  - Polarisation marked with the aid of package shape or with special sign on the package;

Passive components:

- Resistors, capacitors, inductors.
- Package type and dimensions depend on element nominal power not on the specific parameter (eg, resistance).
- Typical values – nominal series obtained with the aid of geometric series with common ratio where n equals to the number of elements in series.
  - Typical series E6, E12, E24, E48, E96 and E192 with defined tolerances 20%, 10%, 5%, 2%, 1% and 0.5%.

- Zero-ohm resistors:
  - Resistors with so called jumpers.
  - The zero-ohm resistors allows to reduce number of viases and layers.
  - Their use can limit the number of layers.
**Elements for surface mount assembly**

**Transistors:**
- Typical packages – SOT (Small Outline Transistor)
- 3 or 4 leaded solutions
- Nominal power depends on the size of the package

**Integrated circuits - SMD:**
- Circuits of small-scale and medium-scale of integration: SO (Small Outline) or SOIC (Small Outline Integrated Circuit) – two parallel row of leads (pins) with pin pitch of 1.27 mm = 50 mils
- Packages usually referred as eg. SO8.
- 1st pin is always marked on the package.
- On PCB layout the 1st pad is rectangular.
- Typical pin number in SO equals to 8 – 32.
- Miniature version: VSO (Very Small Outline) can posses even up to 56 leads.
- Limitations – shear stresses.

**Integrated circuits - SMD:**
- Number of leads can be increase with the aid of wider solutions:
  - PLCC (Plastic Leaded Chip Carrier) usually available with 3” leads with lead pitch of 1.27 mm; up to 84 leads;
  - QFP (Quad Flat Package) usually with 2” leads; lead pitch 1mm to 0.4mm; from 32 to 304 leads;
  - QFN (Quad Flat No-Lead) – leadless packages with special soldering pads at the bottom side.

**ADVANTAGES OF BGA (Ball Grid Array)**
- Number of leads,
- Good mechanical resistivity,
- Elimination of co-planarity problem,
- Limitation of soldering paste usage,
- Small amount of assembly defects,
- More price assembly technology.

<table>
<thead>
<tr>
<th>Number of assembly defects:</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBGA</td>
</tr>
<tr>
<td>QFP(0.635mm)</td>
</tr>
<tr>
<td>QFP(0.5mm)</td>
</tr>
</tbody>
</table>

**PCB arrangement**

- **ZONE I** – electronic element mounting area,
  
- **ZONE II** – connectors
- **ZONE III** – external access
- **ZONE IV** – fixing arrangements
**PCB designing**

**Grid for PCB design**

<table>
<thead>
<tr>
<th>UNIT SYSTEM</th>
<th>METERS</th>
<th>INCHES</th>
<th>MILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>2,5 mm</td>
<td>0,1&quot; = 2,54 mm</td>
<td>100</td>
</tr>
<tr>
<td>Intermediate</td>
<td>1,25 mm</td>
<td>0,05&quot; = 1,27 mm</td>
<td>50</td>
</tr>
<tr>
<td>Secondary</td>
<td>0,625 mm</td>
<td>0,025&quot; = 0,635 mm</td>
<td>25</td>
</tr>
</tbody>
</table>

Mil – unit of length used in PCB designing

1 mil = 1/1000 inch

**Main PCB designing rules**

- Soldering pads for THD must be located in nodes of the designing grid,
- Geometrical centres of SMD must be located in the nodes of the designing grid,
- Tracks should be placed along the grid lines.

**Soldering pads:**

- **NON-PLATED:** D/d = 2,5 + 3
- **PLATED:** D/d = 1,5 + 2

Plated holes should be of 0,15 to 0,30 mm bigger in comparison to non-plated ones

- for d_max = 0,5-0,85mm
- d = \(d_{\text{max}} + 0,10 \pm 0,05\) mm
- for d_max = 0,85-1,10 mm
- d = \(d_{\text{max}} + 0,15 \pm 0,1\) mm
- for d_max = 1,1-2,00 mm
- d = \(d_{\text{max}} + 0,20 \pm 0,1\) mm

**Conductive tracks:**

- Maximum current load;
- Maximum voltage drop along the track length;
- PCB manufacturing technology,
- Standardised track width,
- Parasitic elements (inductance, capacitance)
- Type of substrate (resistivity),
- Environmental conditions (temperature, humidity, pressure),
- Mount technology type,
- Distance between tracks.

**Distance between tracks:**

- Voltage between adjacent tracks,
- Peak voltage value,
- Surface resistance of the substrate.
- Environmental conditions,
- The type of isolating coating
- Electromagnetic interference,
- Type of mount technology
- Manufacturing conditions.

<table>
<thead>
<tr>
<th>Maximum voltage between tracks (V)</th>
<th>Minimum distance [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>0,15</td>
</tr>
<tr>
<td>10-30</td>
<td>0,25</td>
</tr>
</tbody>
</table>

**Soldering pads:**

- Narrow leads
- As narrow as 1/3 of pad width.
- PLATED: PLATED

**Interconnection between soldering pad:**

Geometrical centres of SMD must be located in the nodes of the grid.
EQUIPMENT DESIGN AND MATERIAL ENGINEERING

Connections

**Definition:**
The two metallic elements remain in electrical connection if electrons from crystal lattice of one metal can easily move to the lattice of the other metal.

**Types of connections:**
- permanent
- temporary

**How to obtain a good electrical connection?**
- Natural features of joined metallic elements are:
  - SURFACE ROUGHNESS;
  - INSULATING LAYER (INSULATING LAYERS OF THE THICKNESS OF 0.1 MICROMETERS ARE FORMED ON EVERY METALLIC: Cu, Ag, Al... SURFACE AS A REACTION OF METALS WITH DIFFERENT ATMOSPHERIC COMPONENTS: <E.G. OXIDE>);
  - To obtain a good electric connection, it is necessary to remove the insulating layer from the connected metal surface to minimise resistance; improve electrical conductivity.

**Different joining techniques for permanent connection creation:**
- With additional joining phase:
  - SOLDERING;
  - WELDING;
  - GLUING;
- With contact stresses:
  - WRAPPED;
  - CRIMPED;
  - INSULATION DISPLACEMENT.

Temporary connections are formed only on the bases of contact stresses that are limited by material elasticity.

**Joining technique for permanent connections with additional joining phase:**
- Joining process:
  - SOLDERING — fusible alloy melts at lower temperature than joined metals;
  - WELDING — superficial layers of joining metals melt and create a connection;
  - GLUING — permanent phase change of a glue;
- Removing of isolation layer:
  - FLUX (SOLDERING);
  - DISSOLVENTS (WELDING AND GLUING).

**Joining technique for permanent connections based on contact stresses:**
- Joining process:
  - JOINING METALS SHOULD BE BROUGHT AS CLOSE AS AT THE MOLECULAR DISTANCE
  - DEFORMATIONS ARE CREATED AT THE LEVEL OF MICRO VOIDS
- Removing of isolation layer:
  - STRESSES RESULTING FROM APPLIED PRESSURES
Soldering:
- Introduction of fusible alloy (solder) between joining metals
- Creation of inter-metallic compound after proper heat treatment

Soldering pad
PCB
soldering pad
solder alloy
solder alloy
Cu6Sn5
Sn5Cu3
Cu
Sn

The joining surfaces are wetted,
The diffusion of atoms occurs,
Inter-metallic bonds are created,
Solder can be driven in all the voids.

Solderability – is measured by means of wetting of the surface with the aid of solder with respect to specified conditions.

Solderability – wetting angle:
Wetting angle vs. the shape of the formed meniscus

Basic component of solders is tin (Sn);
The allotropic transformation of white tin into gray tin can occur at temperature below 13.2°C => “tin disease”;
Counteraction against “tin disease” – addition of 5% lead (Pb); 0.5% antimony (Sb) or 0.1% bismuth (Bi)

Low melting temperature (183°C);
Pb additive reduces dissolvability of Cu and Ag with the solder;
Strong mechanical bonds of: Cu, Sn, Pb, Ag, Au (Pb reduces the surface tension of tin and improves wetting of the surface);
High resistivity against oxidation of soldered connections;
Low resistivity;
Good knowledge of technological processes of soldering with SnPb.
The Restriction of Hazardous Substances Directive 2002/95/EC, popularly abbreviated as RoHS, took effect on 1 July 2006.

Some exceptions:

**Necessity to replace SnPb:**
- Solidus temperature higher about 30°C than for SnPb;
- Much harder and stiffer material than SnPb;
- High Sn content gives rise to tin whiskers;
- Wider failure distribution;
- Fatigue resistance decreases with Ag content;
- Mechanical shock resistance increases with Ag content.

**Lead-free solders:**

<table>
<thead>
<tr>
<th>Sn</th>
<th>Pb</th>
<th>Ag</th>
<th>Cu</th>
<th>In</th>
<th>Bi</th>
<th>Ga</th>
<th>sol.</th>
<th>liq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>37</td>
<td>3</td>
<td>0,5</td>
<td>3</td>
<td>0,5</td>
<td>217</td>
<td>183</td>
<td>183</td>
</tr>
<tr>
<td>62</td>
<td>36</td>
<td>3</td>
<td>0,5</td>
<td>3</td>
<td>0,5</td>
<td>217</td>
<td>179</td>
<td>179</td>
</tr>
<tr>
<td>92</td>
<td>3,3</td>
<td>4,7</td>
<td>210</td>
<td>215</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>3,3</td>
<td>3,7</td>
<td>206</td>
<td>211</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>83,4</td>
<td>4,1</td>
<td>0,5</td>
<td>185</td>
<td>195</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>92</td>
<td>0,5</td>
<td>6</td>
<td>0,5</td>
<td>209</td>
<td>214</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>96,5</td>
<td>3,5</td>
<td>217</td>
<td>219</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95,7</td>
<td>3,6</td>
<td>0,7</td>
<td>217</td>
<td>218</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95,5</td>
<td>4,0</td>
<td>0,5</td>
<td>217</td>
<td>219</td>
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</tr>
<tr>
<td>96</td>
<td>2,5</td>
<td>0,5</td>
<td>1</td>
<td>214</td>
<td>218</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>96,5</td>
<td>3,5</td>
<td>215</td>
<td>221</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fluxes**

- Proper application should be possible (required state);
- Good wetting properties;
- Must be able to destroy the tarnish;
- Should start to act at certain temperatures lower that solder melting temperature and higher than temperatures during dispensing (80°C -100°C);
- It should protect the surface till the end of process soldering;
- Cannot be toxic;
- Should leave no residues on the soldered connections.

**Flux demands:**

- No-clean, low solid (do not require any cleaning after soldering process);
- Based on organic and inorganic resins (e.g. rosin),
  - Cleaning is advised;
  - Water-soluble,
  - They leave the residues that MUST be cleaned after soldering;

**Fluxes can be classified into one of three groups:**

- Based on organic and inorganic resins (e.g. rosin),
- Cleaning is advised;
- Water-soluble,
- They leave the residues that MUST be cleaned after soldering;

**Solder pastes:**

They are used in reflow soldering.

**Composition of solder paste:**

- SOLDER – powder form of granules of the alloy (about 90% of weight; 50% of volume)
- CARRIER (about 10% of weight; about 50% of volume)
  - Flux
  - Dissolvent
  - Others
Basic requirements of solder pastes:

- The individual powder particles of the solder alloy should have a homogeneous distribution of the metal within the paste;
- It should develop an adhesive action in order to hold the components in place up to the end of reflow process;
- It must not tend to solder balling;
- It must maintain its shape during curing and reflow;
- It must have sufficient activity.

Solder paste – reological properties:

- Viscosity – paste should be a thixotropy fluid => a time-dependent viscosity change should be observed while subjected to mechanical stresses;
- Slump – a tendency to spread after dispensing
- Working life (including coalescence phenomenon)

Soldering processes

Soldering techniques:

- Wave Soldering
- Reflow Soldering
- Manual Soldering

Wave soldering

Surface mount technology – technological processes preceding the wave soldering:

- Application of adhesives (syringe dispensing, stencil printing)
- Component placing
- Adhesive curing
- PCB rotation

Stages of wave soldering:

- Fluxing the board
- Pre-heating
- Wave soldering

Wet flux film thickness

3 – 20 micrometers
### Wave soldering

**Stages of wave soldering:**
- Fluxing
- Pre-heating
  - **GOALS:**
    - Pre-heating of the board (to eliminate thermal shock that can result in damage of heat -sensitive components and can cause twist and bow of the board; shorter soldering time).
    - Evaporate the flux solvents;
    - Activating the flux;
  - **HEAT sources:**
    - Hot circulating air;
    - Infrared radiation.
- Wave soldering

### Wave soldering

- **SINGLE WAVE**
  - SMOOTH WAVE (UHINAK) - PCB should move with the same speed as the solder is flowing => elimination of „ciddles“; drawback: shadow effect;
  - TURBULENT WAVE - elimination of shadow effect; drawbacks: unwanted solder remains on the connections; bridging, solder balls;

- **DUAL WAVE**
  - SMOOTH +TURBULENT WAVES (the first one is a turbulent wave that causes full wetting and enables the molten solder to drive between the components; the second one is a smooth wave that controls the meniscus of each joint)

### Reflow soldering

**Surface mount technology – technological processes preceding the reflow soldering:**
- Solder paste application
  - Syringe dispensing – needle diameter at least 7-times (generally 10-times) greater than solder particle size;
  - Screen printing (small resolution);
  - Stencil printing,
- Component placing

### Reflow soldering

**Stages of reflow soldering:**
- Pre-heating – first phase
  - Equilibrating
  - Reflow
  - Cooling
- Temperature should be slowly raised (initial gradient 2°C/s; next 3-4°C/s) up to 120°C - 160°C;
- No soldering is observed;
- To activate the flux activation;
- To preserve board thermal shock.
Stages of reflow soldering:
- Pre-heating
- Equilibrating
- Reflow
- Cooling

- To obtain thermal equilibrium; temperature 145-155°C, time 30s-150s;
- Vapourization of moisture and volatiles on the board.

Electrical and mechanical bonds
- Wetting action must take place.

Proper solidification must take place.

Systems for reflow soldering:
- Radiation systems,
- Natural convection systems
- Forced convection systems
- Combined systems (CONVECTION + RADIATION)

Reflow soldering with the aid of convection systems:
- More uniform heating;
- Temperature gradients minimalisation across the PCB (with near infra-red one can obtain 19°C; with improper population of PCB, one can obtain even 30°C; Load-free technology requires that temperature gradients should be maintained below several °C);
- Better heat transfer efficiency.
Connections based on contact stresses

**Wrapped connections:**
- A solderless connection made by wrapping 6 - 9 turns of bare wire around a terminal under tension.
- Terminal must be sharp corner usually rectangular element.
- Wrapped wires must be circular!!!
- The wire diameters should be in the range 0.15 to 1.0 mm.

*Properties:*
- Gas-tight solutions;
- High durability (stresses are half reduced after 40 years);
- High range of currents and voltages (limitation wire diameter);
- High reliability in every environment;
- Cold-working technique;
- Small resistance of the connection;
- High resistivity to mechanical shocks and vibrations;
- Can be re-worked;
  - Can operate up to 70°C;
  - Automatic manufacturing brings the best results;
  - Limitations on wire diameters.

**Crimped connection:**
- Stripped end of a stranded (usually copper) wire is inserted into a terminal, which is then mechanically deformed / cramped tightly around the wire.
Connections based on contact stresses

Crimped connections - properties:
+ Gas-tight permanent solutions;
+ High durability;
+ High range of currents and voltages;
+ High reliability in every environment;
+ Cold-working technique;
+ Small resistance of the connection;
+ High resistivity to vibrations;
- Cannot be re-worked;
- Can be used only for stranded wires.

Insulation displacement connectors:
+ The wires are pressed into fork-shaped opening in the terminal.
+ The opening cut through the insulation to contact the conductor.

EQUIPMENT DESIGN AND MATERIAL ENGINEERING

Assembly faults and methods of inspections

Soldering faults

- Delamination,
- Geometrical effects,
- Inaccurate placements/misalignment,
- Shadows,
- Bridges,
- Tombstone effect,
- Balling and beading effects, splashes,
- Disturbed solder joints.

Soldering faults

DELAMINATION/BLISTERING/OVERHEATING:
- Problems of the laminates exposed to excessive heat or entrapped moisture;
- Separations or bubbles between resins and copper foils;
- Laminate colour can change; black spots can occur;

GEOMETRICAL EFFECTS:

Different places at PCB are characterised by different soldering properties
**SHADOWS:**
- The component body prevents the solder from reaching the soldering pad;

**Solutions:**
- Terminal shape;
- Turbulent or dual wave soldering;
- Proper electronic elements layout with respect to conveying direction;

---

**BRIDGING:**
- Bridges is a short that occurs when an excess of solder makes an unwanted electrical connection.

**Solutions:**
- Depends on soldering method;
- Can be introduced at the designing or manufacturing levels.

---

**BRIDGING:**
- Wave soldering - solutions:
  - Use inclined conveyor,
  - Control the shape and the contact time of the wave and the soldered PCB (extension plates; dual wave).

---

**BRIDGING:**
- Reflow soldering:
  - Too big amount of soldering paste on a soldering pad;
  - Soldering paste printing accuracy (misalignment of stencil and the lands, smearing of the paste);
  - Improper parameters of the soldering paste (eg: too old paste, mismatch of used material properties, etc.).
Soldering faults

BRIDGING:
Reflow soldering - solutions:
- Better accuracy and resolution of soldering paste printing,
- Proper amount of paste is deposited on the land,
- Decrease the heating rate at the pre-heating stage,
- Usage of fluxes with shorter wetting time.

Soldering faults

TOMBSTONE EFFECT
Solutions:
- Design rules should be checked,
- Quality of printing and solderability should be verified,
- Heating rate should be decreased or heating time should be increased at the pre-heating stage,
- Usage of fluxes with longer wetting time (bridging may occur).

Soldering faults

TOMBSTONE EFFECT
- The small chip-element during reflow soldering process is detached from PCB at one side while remaining attached at the other side.

Main reasons:
- Improper design of soldering pads,
- Poor accuracy or pressure during element placement,
- Improper amount of soldering paste on the land,
- Non-uniform wetting conditions for two soldering pads.

Soldering faults

SOLDER WICKING
Solutions:
- Proper soldering profile for the reflow process,
- Planarity of leads should be ensured,
- Fluxes with activation temperatures close to the reflow temperatures should be applied,
- Element leads should be coated with alloys characterised by higher melting temperatures than the melting temperature of soldering alloy.

Soldering faults

SOLDER WICKING
- Leads covered with tin is wicking solder from the soldering pad;
- The phenomenon is mainly caused by temperature gradient between the element lead and PCB;
- The lead with a higher temperature melts the solder earlier and the solder is wicking by hotter part.

Soldering faults

BALLING/BEADING EFFECTS
Main reasons:
- Too huge amount of fine particles within the paste (below 25µm),
- Improper curing of solder resist or not fully cured resin of the laminate,
- Presence of non-soluble contaminants in the solder,
- Sputtering due to use of wrong fluxes,
- Bad soldering profile,
- Too high pressure during element placement,
- Wrong design of soldering pads.
Soldering faults

**BALLING/BEADING EFFECTS**

Solutions:
- Re-soldering of the PCB (faults resulting from incomplete curing),
- Proper design of soldering mosaic,
- Proper cleaning of elements and working area,
- Proper soldering profile,
- Eliminate the reasons causing the phenomenon.

**DISTURBED SOLDER JOINTS**

- Disturbed solder joints are usually called „cold” joints;
- They may result from:
  - any movement of the solder during solidification;
  - inadequate heating during soldering process;
  - lack of leads co-planarity;
  - contaminations either in solder or at the soldering pads.

---

**Reflow soldering**

<table>
<thead>
<tr>
<th>Faults [%]</th>
<th>Paste Printing</th>
<th>Element Placing</th>
<th>Soldering</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Quality control**

Quality control programme can be oriented on:
- Failure protection
  - Incoming Material Control - all incoming raw materials are sampled and inspected;
  - In Process Control - identification of critical points in the production flow;
  - Complete Production Control - the final test is made on completed boards;
- Failure detection
  - The inspection is performed after assembly process

„The earlier the failure is detected and fixed the lower production cost will be“

---

Quality control test can be classified into two groups:
- **IN-LINE**
  - Quality control at different critical points within single production line;
  - Automatic or semi-automatic systems usually operating in closed-feedback loop;
  - Dedicated application (high cost);
- **OFF-LINE**
  - Located close to several production lines;
  - More elastic solution suitable for testing elements at different points of production flow (slow operation, low cost);
  - New product implementation, modifications in the production line.
Quality control

Quality control methods:

- MVI – Manual Visual Inspection
- AOI – Automatic Optical Inspection
- IR – Infrared Thermal Imaging System
- AXI – Automatic X-ray Inspection
- ICT – In-circuit Test
- FT – Functional Test

Quality control

Visual Inspection MVI:

- Usually, it involves a study with the unaided eye or with magnification (standard magnification 2X to 10X; higher demands e.g.: for plated through-holes even up to 100X);
- Human:
  - 1/500th of a second to recognize an object;
  - Human eye can recognize easily variations in the object;
  - Human eye can readily adopt to new situations;
- Visual access is required.

Quality control

Optical Inspection AOI:

- Can be placed in different points in the production flow;
- Only the questionable components are sent for MVI test -> an operator is necessary;
- Failures that can be detected:
  - Missing or twisted elements, improper element polarisation, tombstoning and billboardingle effects;
  - Bridges, misalignments;
  - Geometrical effects;

X-ray inspection - AXI:

- X-ray inspection allows to examine the areas that are not available for optical inspection systems;
- X-ray inspection systems are based on X-ray blocking characteristics of different materials; hence, the images dependent on different material densities are obtained.

Non-destructive method with oblique view;
High magnification, high resolution method;
Densely packed board can be inspected;
Failures that can be detected:
  - Bridges, shorts and openings;
  - Lifted leads;
  - Missing or moved elements, tombstoning and billboardingle effects;
  - Missing balls or improper joints;
  - Defects of BGA or flip-chip elements.

The paste printing with printing faults should be cleaned and the printing process should be repeated.
Comparison of AOI and AXI systems:

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<th>AOI</th>
<th>AXI</th>
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Application of different inspection systems vs. PCB volume and complexity:

Quality control testing strategy depends on:

- Complexity of PCB (types of packages and number of leads; lead pitch);
- Variety and size of production series;
- Quality and testing time (how much time do you need to detect a defect?);
- Inspection cost (price of control system, programming, maintenance and service etc.).

Detectability of different faults with the aid of different test

<table>
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<tr>
<th>METHOD</th>
<th>SHORT</th>
<th>OPEN</th>
<th>SHORTS</th>
<th>OPENINGS</th>
<th>SIMULATED</th>
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DETECTABILITY: full - partial - none