TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

Hardware Design for Embedded Systems

Embedded Systems Engineering WS10

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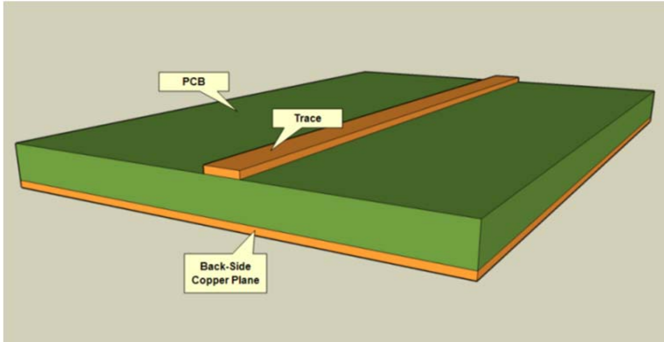
Real-Time Systems Group

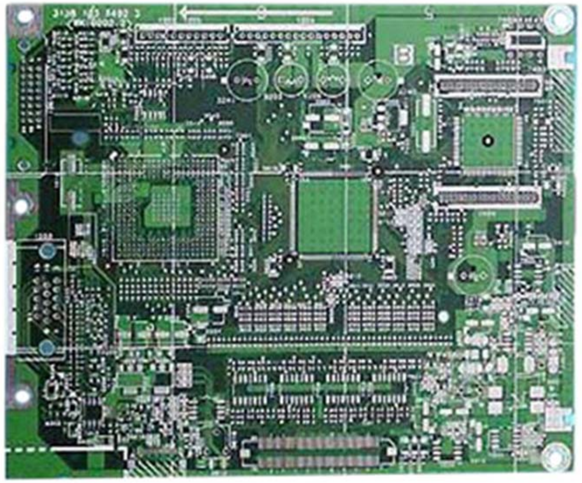
Overview

- **Printed Circuit Boards (PCBs)**
- Workflow for designing and manufacturing PCBs
- „Ideal passive components“ and simplified ECD for a circuit path
- Noise, shielding, pitfalls, etc.
- Further references

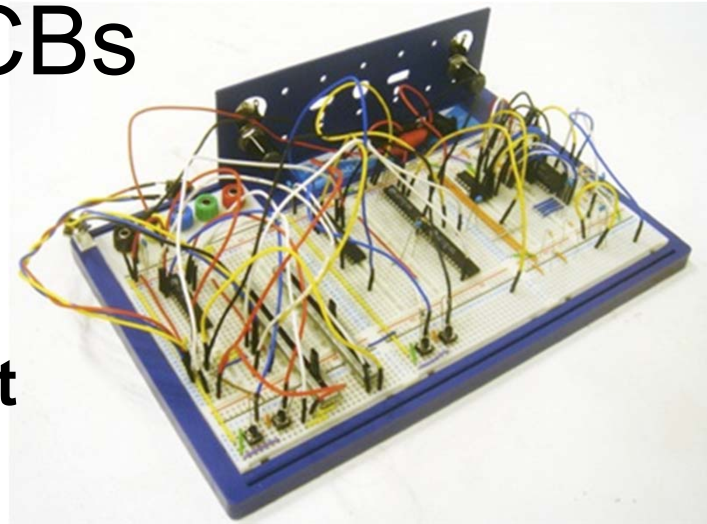
Printed Circuit Boards (PCBs)

- **Substrate** (e.g., epoxy and cotton paper, epoxy and woven glass) plated with **conducting layers** (e.g., copper)
  - different substrate types exhibit different characteristics w.r.t. humidity absorption, thermal fluctuation, leakage current, HF properties, etc.





Breadboards and PCBs



- A *breadboard* (protoboard) is a construction base for a **one-of-a-kind electronic circuit**
- Initial costs (e.g. design cost) of PCBs are typically higher than the cost of breadboard constructions
  - PCBs enable faster fabrication and assembly, better characteristics w.r.t. EMC, etc.
  - careful design, in particular for EMC and HF properties, saves the costs of subsequent improvements

Printed Circuit Boards (PCBs) (2)

- Multiple layers (e.g. thickness of 35µm, 70µm, …)
  - **Single-layer** (used in cheap consumer electronic devices) – easy and cheap fabrication, cheap materials, bad EMC characteristics
  - **Dual-layer** – design and fabrication with reasonable effort, more freedom for routing
  - **Multi-layer** boards (up to 12 layers in mobile phones) – usually dedicated layers for power supply and ground, feasible for highly integrated boards, good EMC characteristics
- Solder mask (negative mask)
- Position prints

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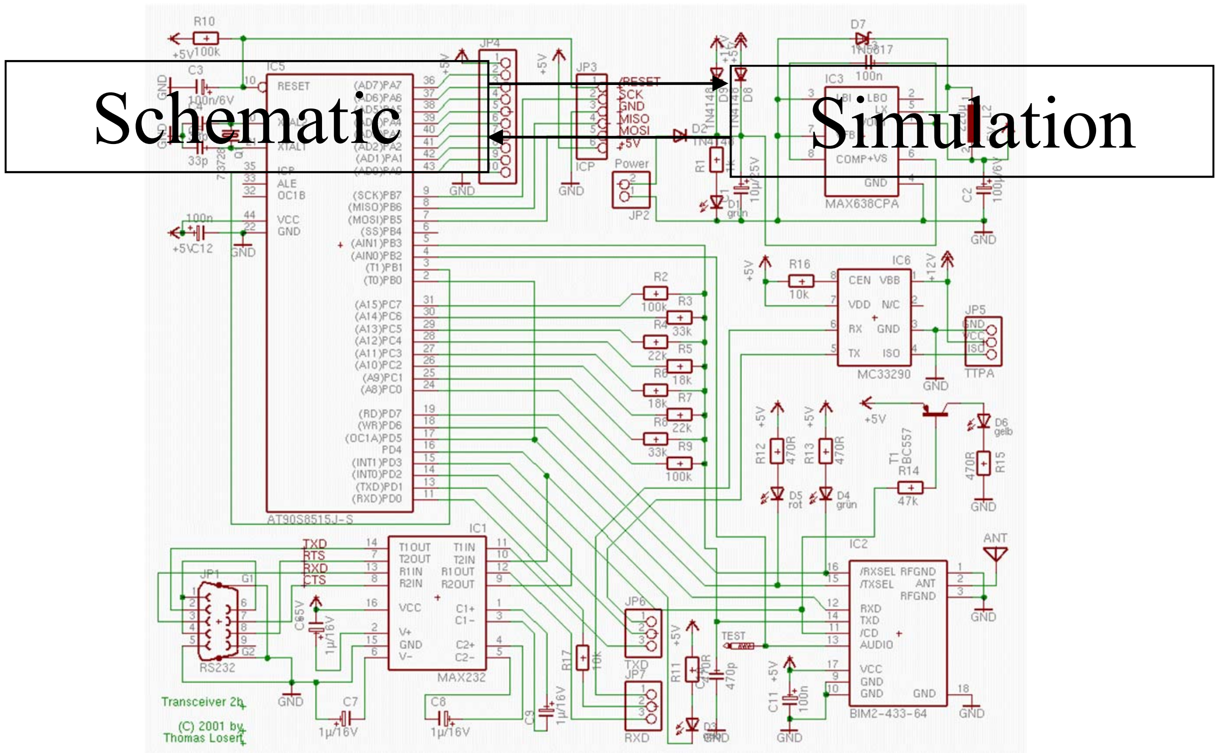
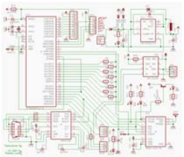
Workflow for Designing a PCB

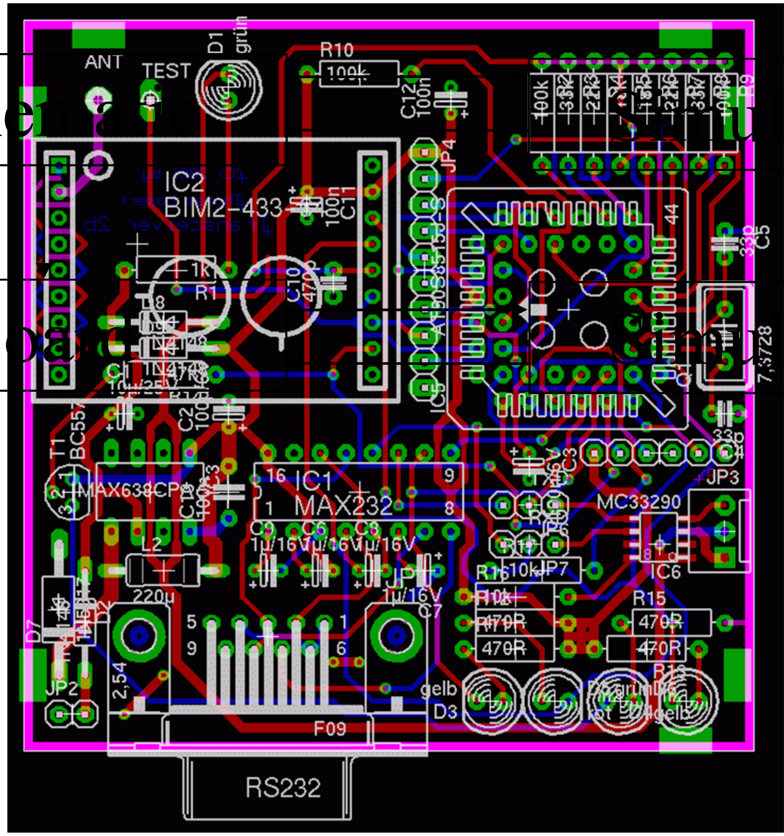


Workflow for Designing a PCB

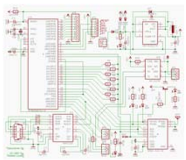


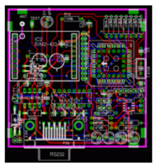
Sche… …atic | …ation

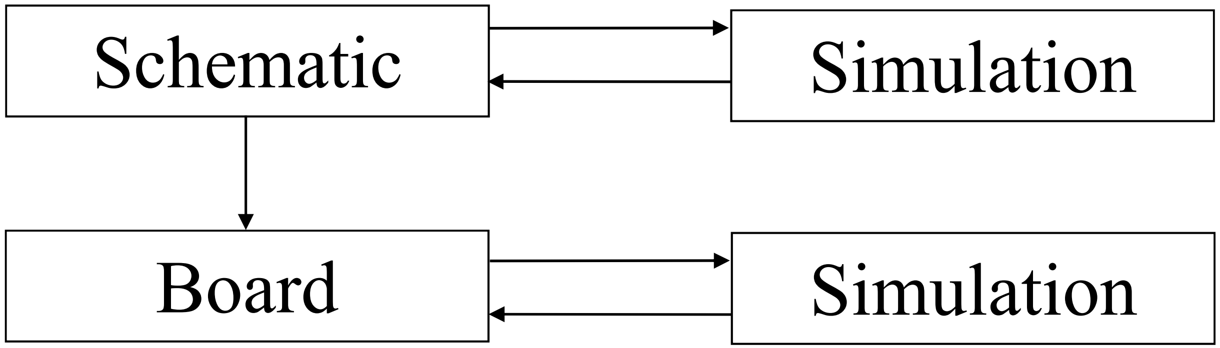
B… | …ation



Workflow for Designing a PCB

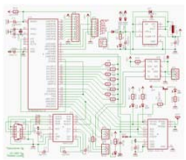


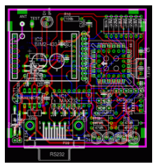


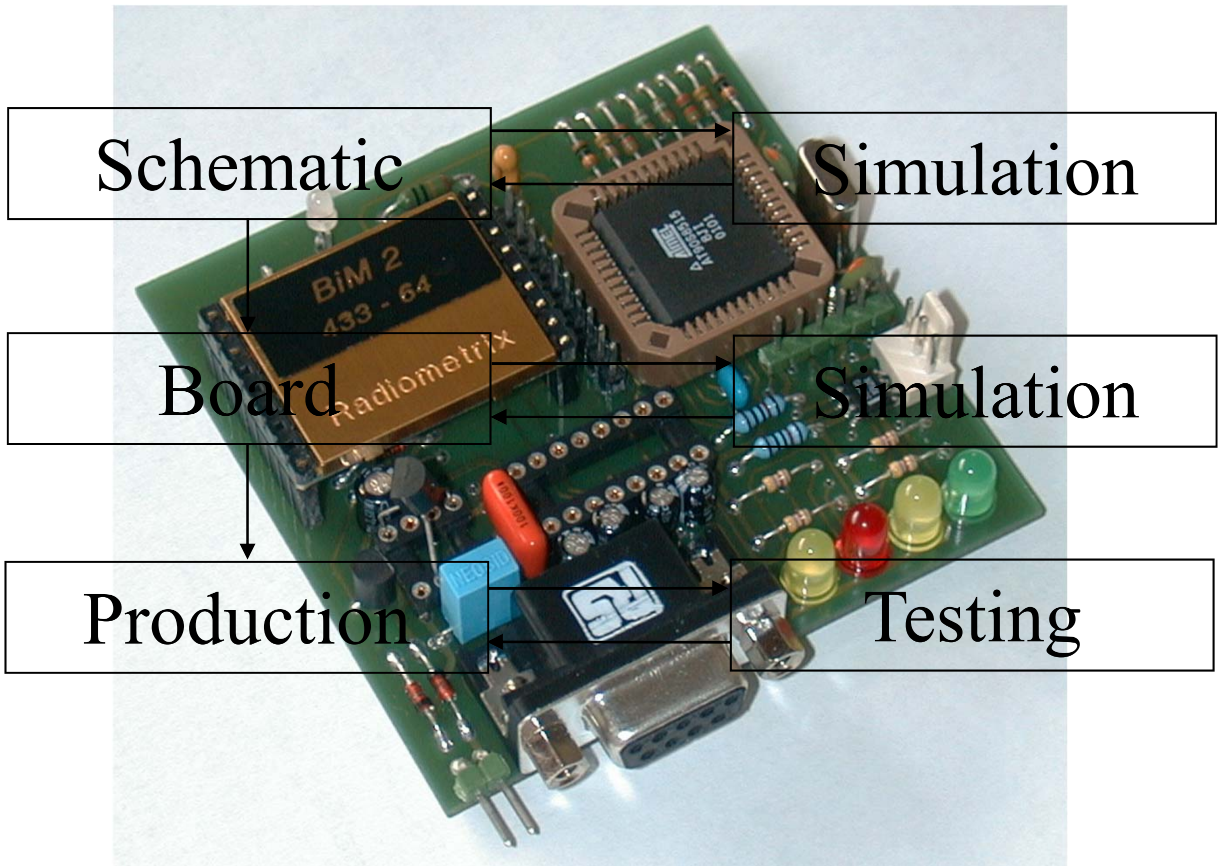


1. Manual placement of devices
   (e.g. quartz next to µC)
2. Manual routing of critical paths
   (e.g. power supply, clock)
3. Determination of mounting holes
4. Execution of auto-router
5. Subsequent improvements
   (e.g. ground planes)
6. Labeling (e.g. version number)
7. Design rule check (e.g. track width)

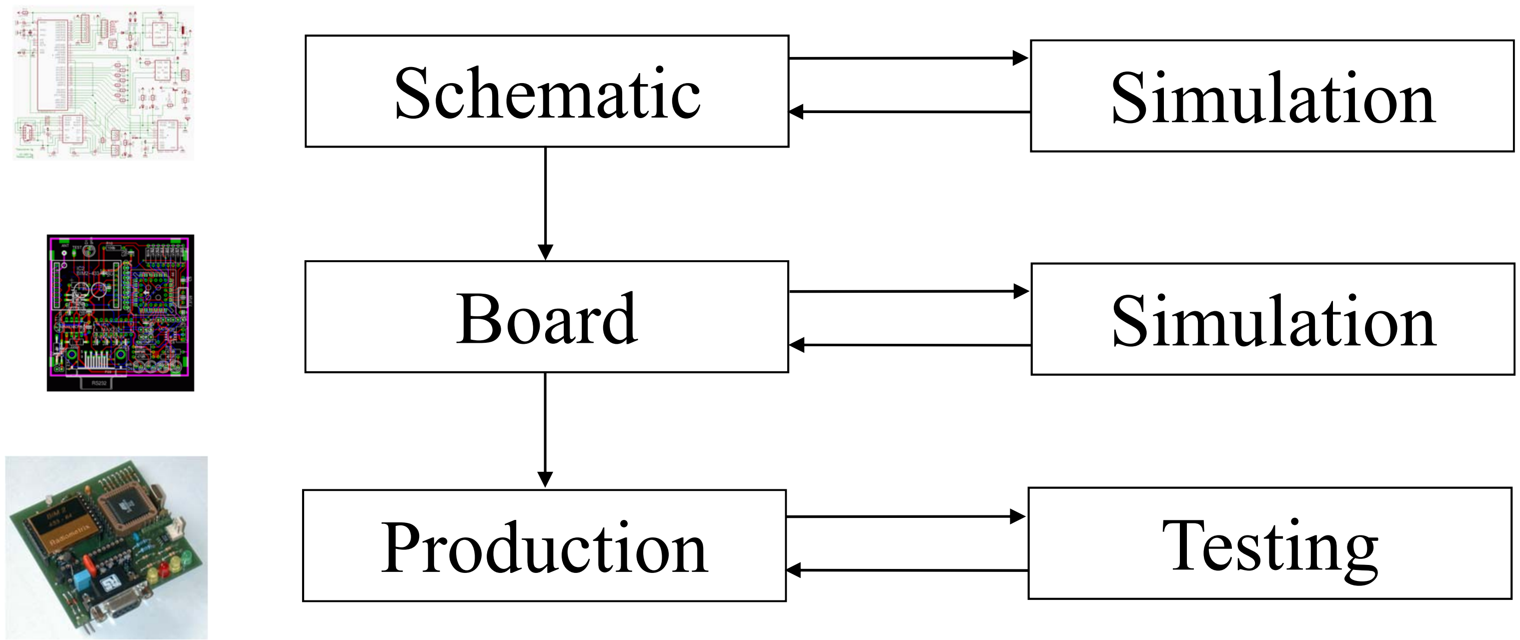
Workflow for Designing a PCB







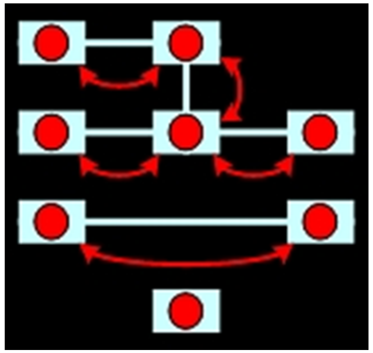
Workflow for Designing a PCB



Line Testing / Short Circuit Testing

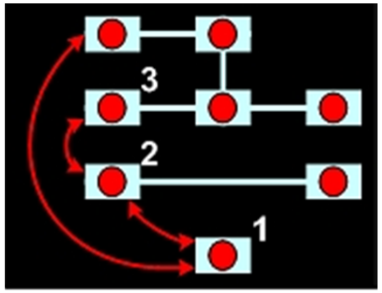
Line Testing

- Test connections, e.g., resistance
- Measure presence of current
  - Measurement < 10 Ω → Good connection
  - Measurement > 10 Ω → High-resistive connection
  - Measurement > 2 MΩ → Circuit break



Short circuit testing

- Test differnet nets against each other
- Measure absence of current
  - Measurement > 2 MΩ → No short circuit
  - Measurement < 2 MΩ → High-resistive short circuit
  - Measurement < 100 Ω → Short circuit



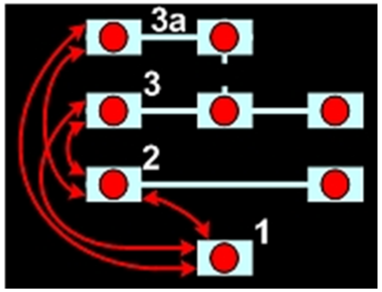
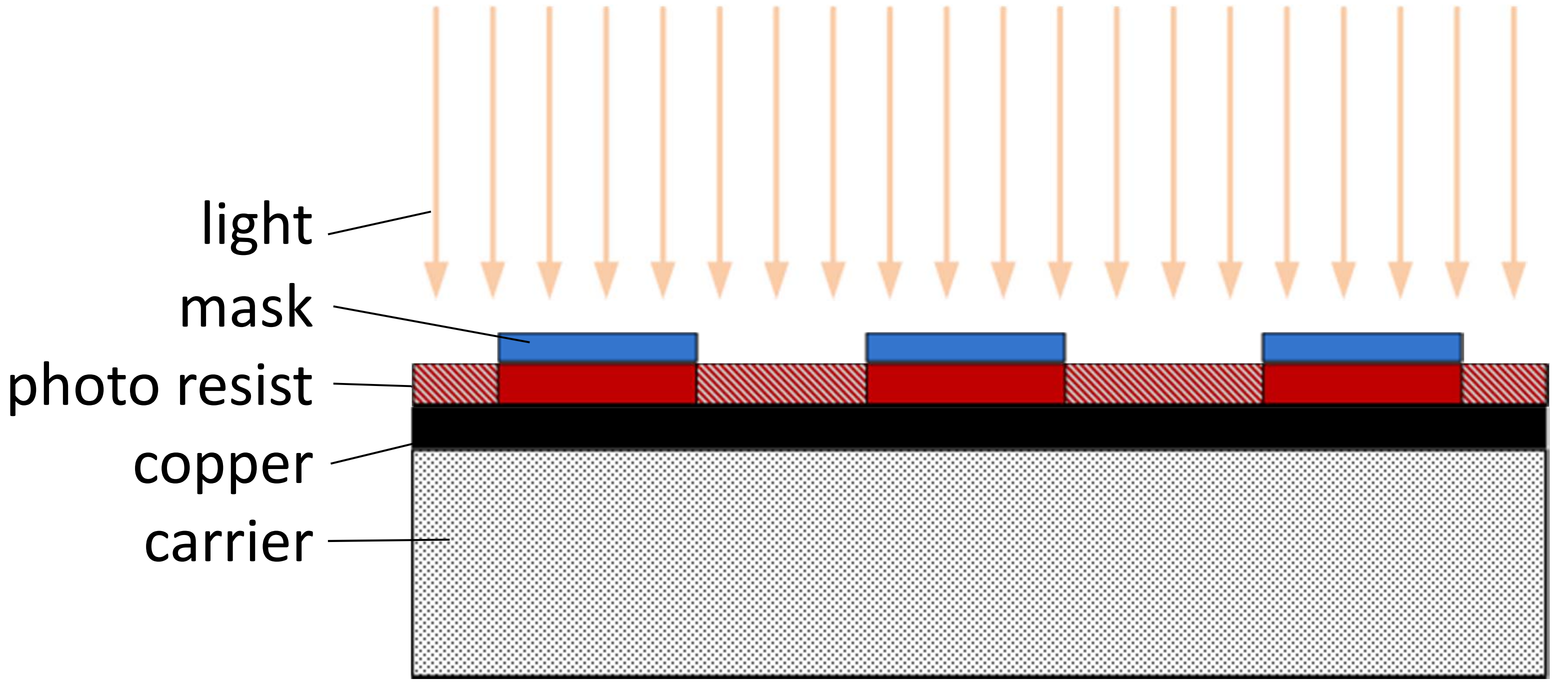
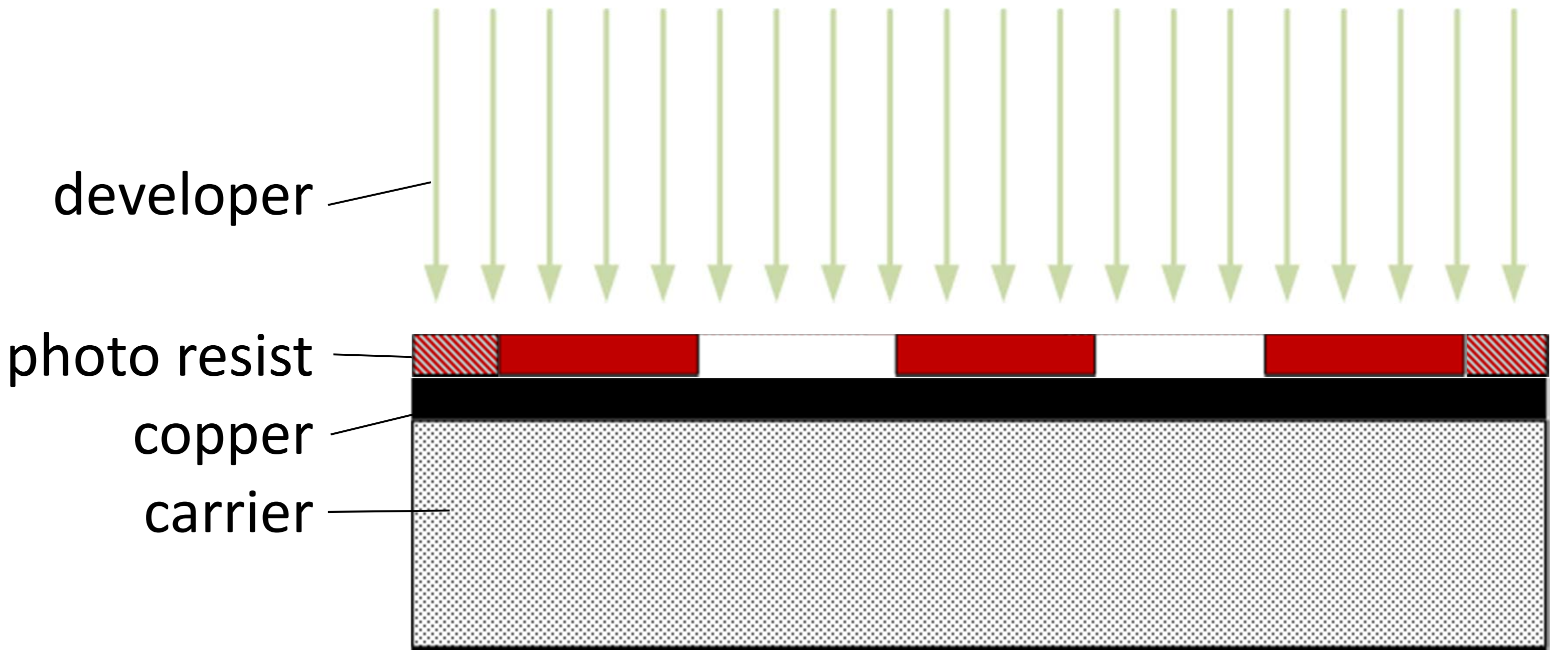


Photo – Positive – Process



The dark areas of the mask remain on the carrier.

Photo – Positive – Process



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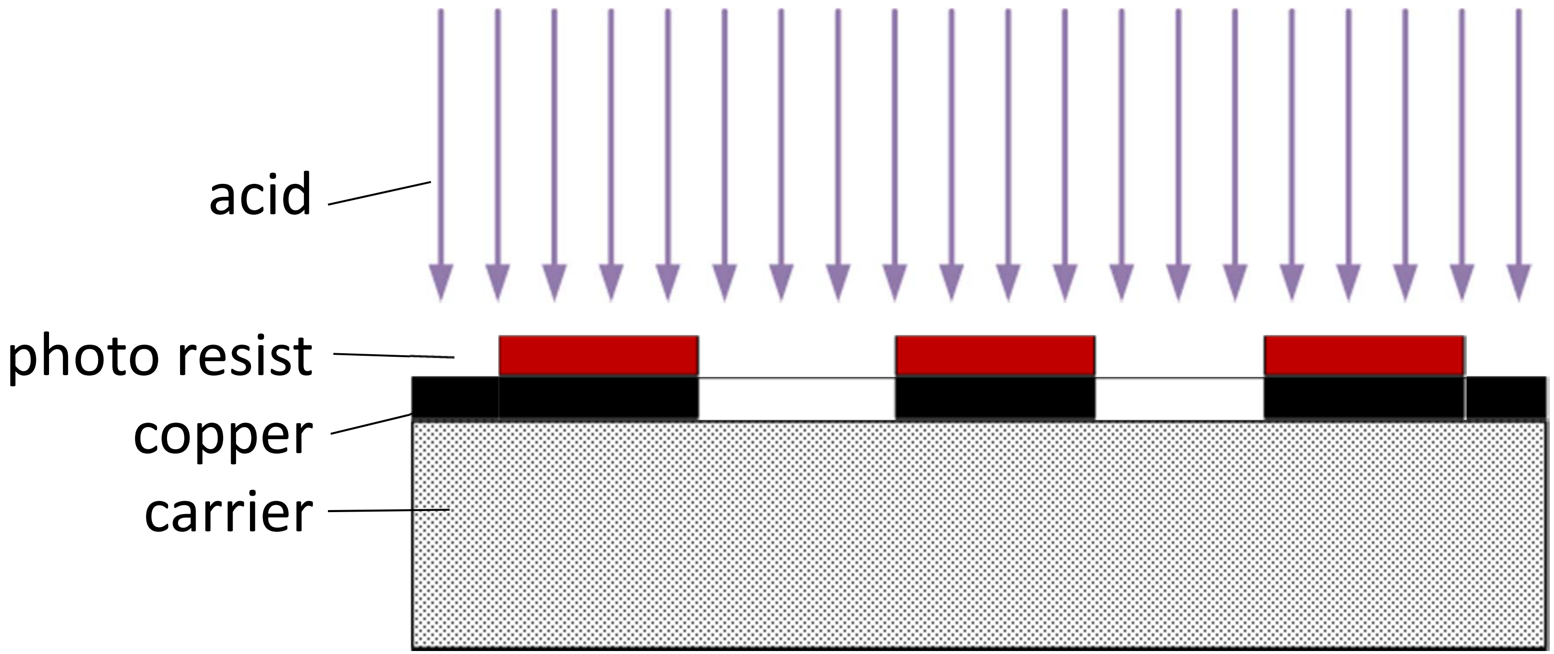

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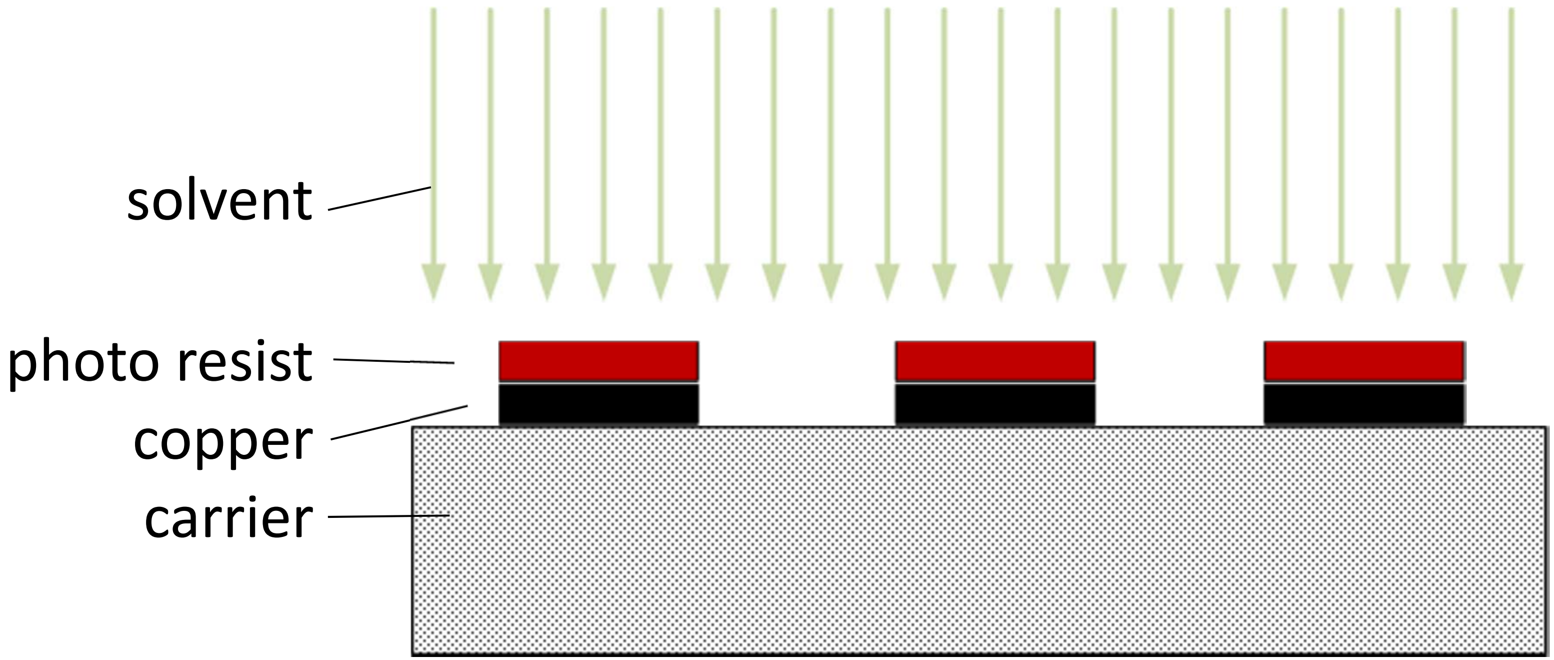
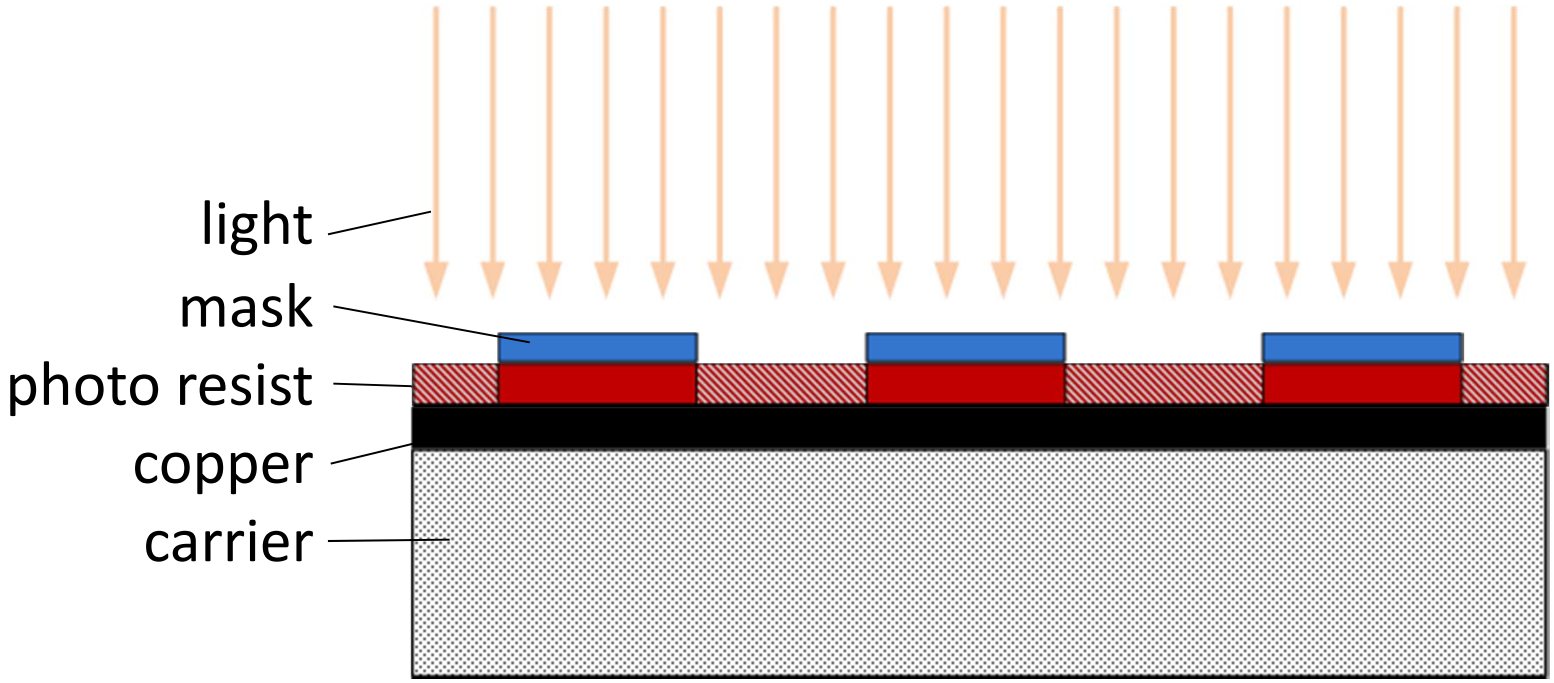


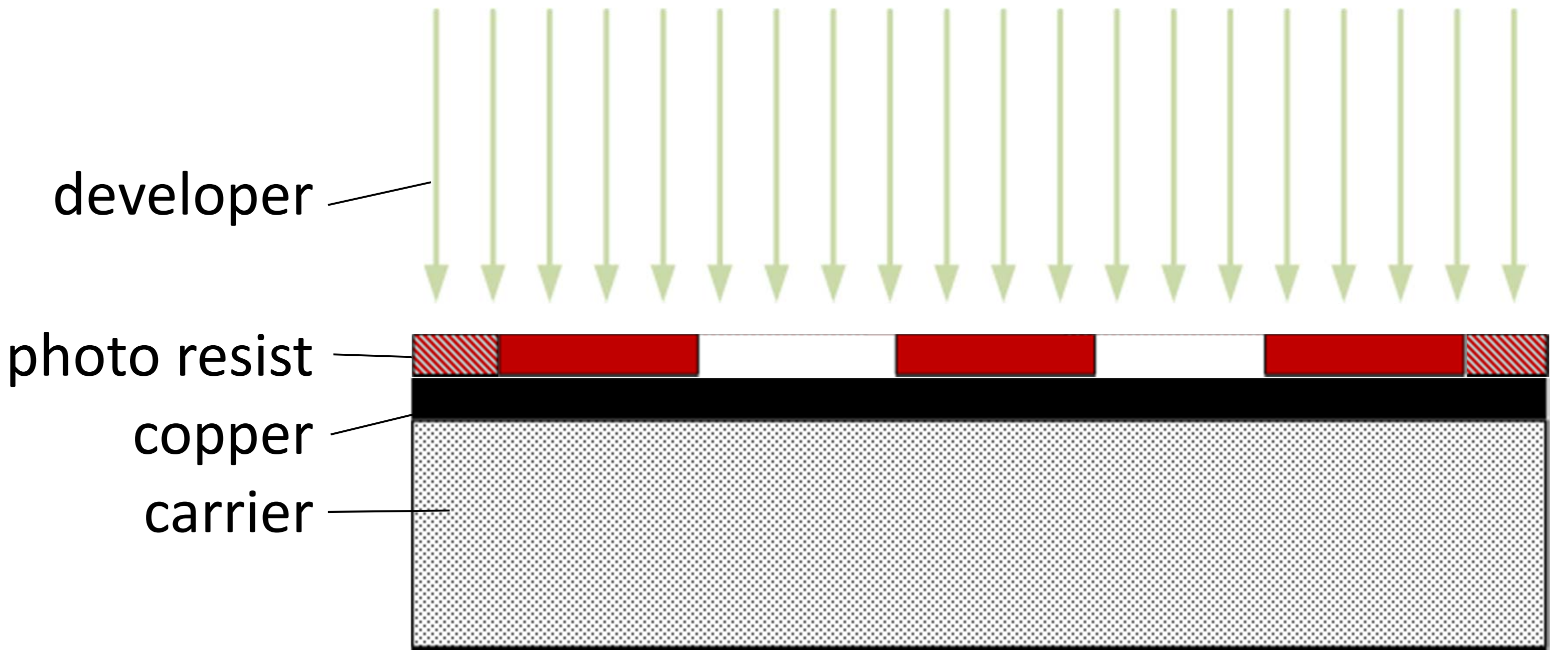
The dark areas of the mask remain on the carrier.

Photo – Negative – Process



The areas under the mask are removed by cauterization.

Photo – Negative – Process



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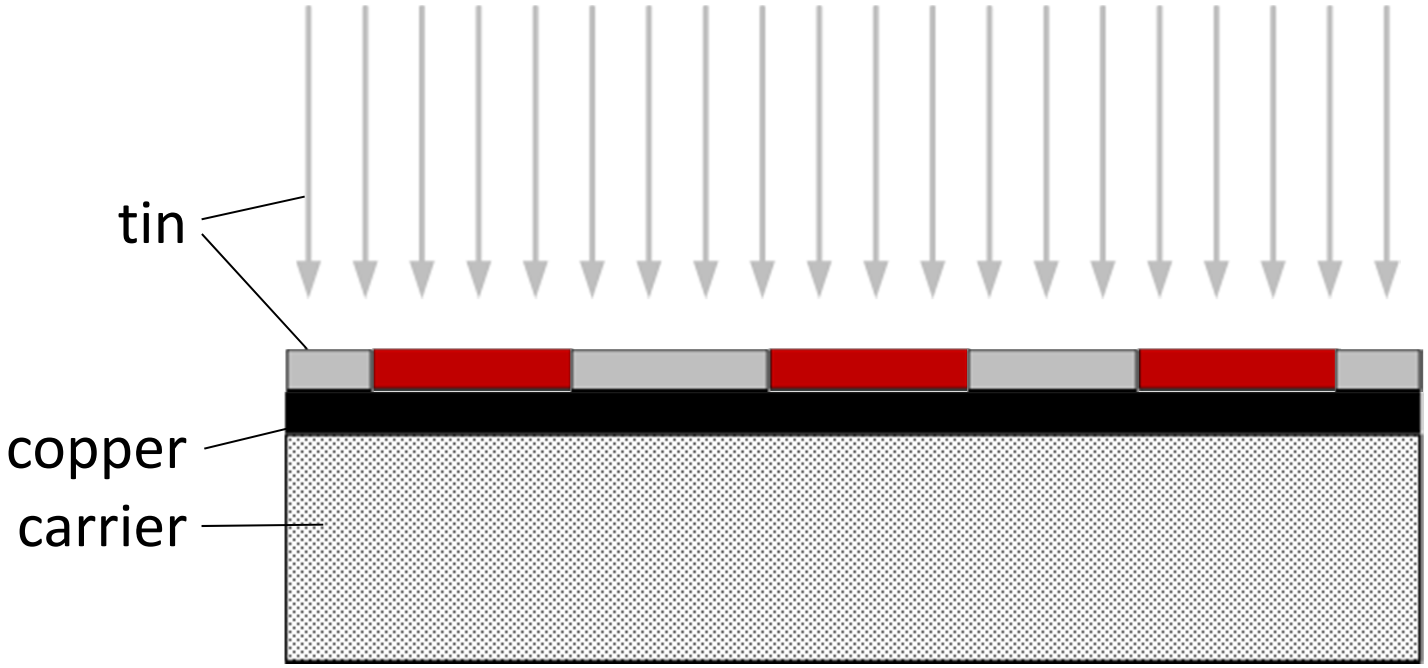

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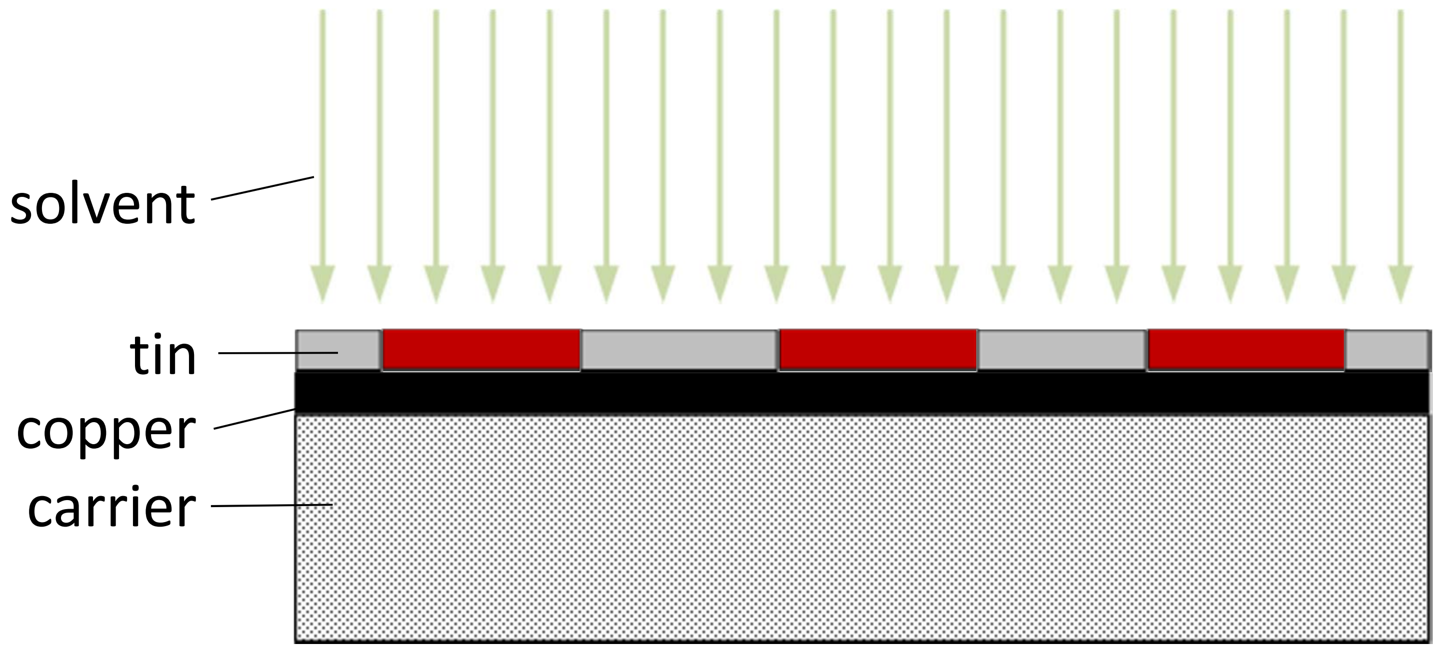

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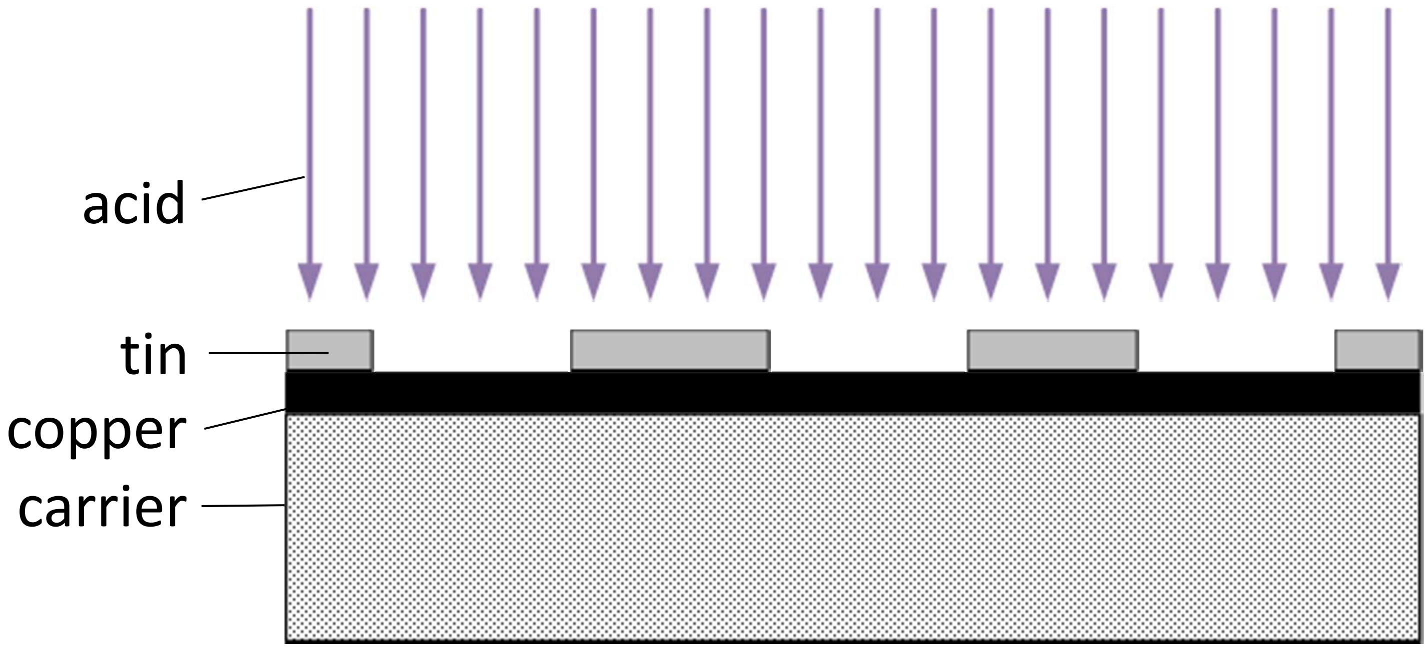

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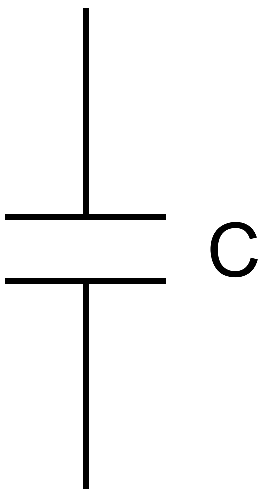
Crash-Course „ideal passive Components“

- There are no ideal components in reality, designers have to deal with (parasitic) effects
- Real components (and also a piece of conductor path) can be modeled as a circuit consisting of ideal components.
  - Ohmic Resistance „R“
  - Capacitor „C“
  - Coil „L“
- Close to the technically achievable limits, parasitic effects of „ideal passive components“ gain in importance

Ideal Ohmic Resistance „R“

- resistance independent from frequency
- current results in voltage drop $U = I \cdot R$
- current results in heat dissipation $P = U \cdot I$

Ideal Capacitor „C“

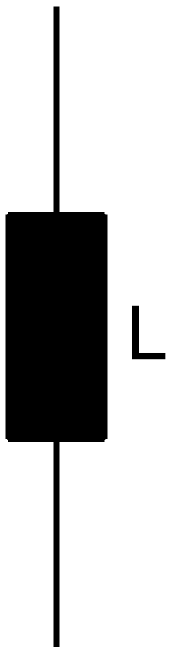


- reactance depends on frequency:

$$X_C = \frac{-1}{2 \cdot \pi \cdot f \cdot C}$$

- acts as open-circuit for DC voltage or AC voltage with low frequency
- acts as short-circuit for AC voltage with high frequency
- energy can be stored and restored in the electric field
- no heat dissipation

Ideal Coil „L“



- reactance depends on frequency:

  $$X_L = -2 \cdot \pi \cdot f \cdot L$$

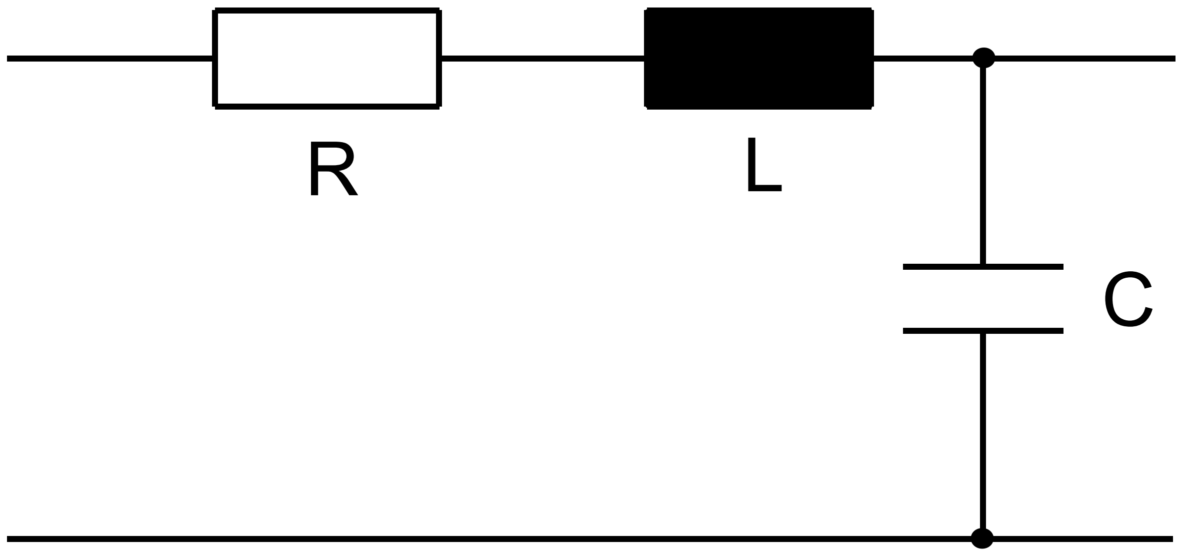
- acts as short-circuit for DC voltage or AC voltage with frequency → very low
- acts as open-circuit for AC voltage with frequency → very high
- energy can be stored and restored in the electromagnetic field
- no heat dissipation

Circuit Paths on a PCB

… are no short-circuits, but are …

- Resistors - dependent from length and cross sectional area
- Coils - dependent from length and geometry
- Capacitors - dependent from length and distance to other conductors

Simplified Equivalent Circuit Diagram for a Small Piece of a Conductor Path



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Noise Sources (1/2)

Internal noise is caused mostly by signals with high frequency (e.g. Oscillator of Microcontroller) or high currents (e.g. power supply)

- Minimize length of circuit paths that could act as antennas for noise signals (e.g., ground-planes)
- Maximize distance to sensitive signals (e.g. measurement signals), separation analog and digital circuits
- Subdivide the system in (nested) „System Zones“ and use filters for blocking noise at the boundaries (e.g. supply)
- Eliminate noise sources (e.g., no floating input pins)

Noise Sources (2/2)

External noise is received mostly through I/O-connectors or electromagnetic waves

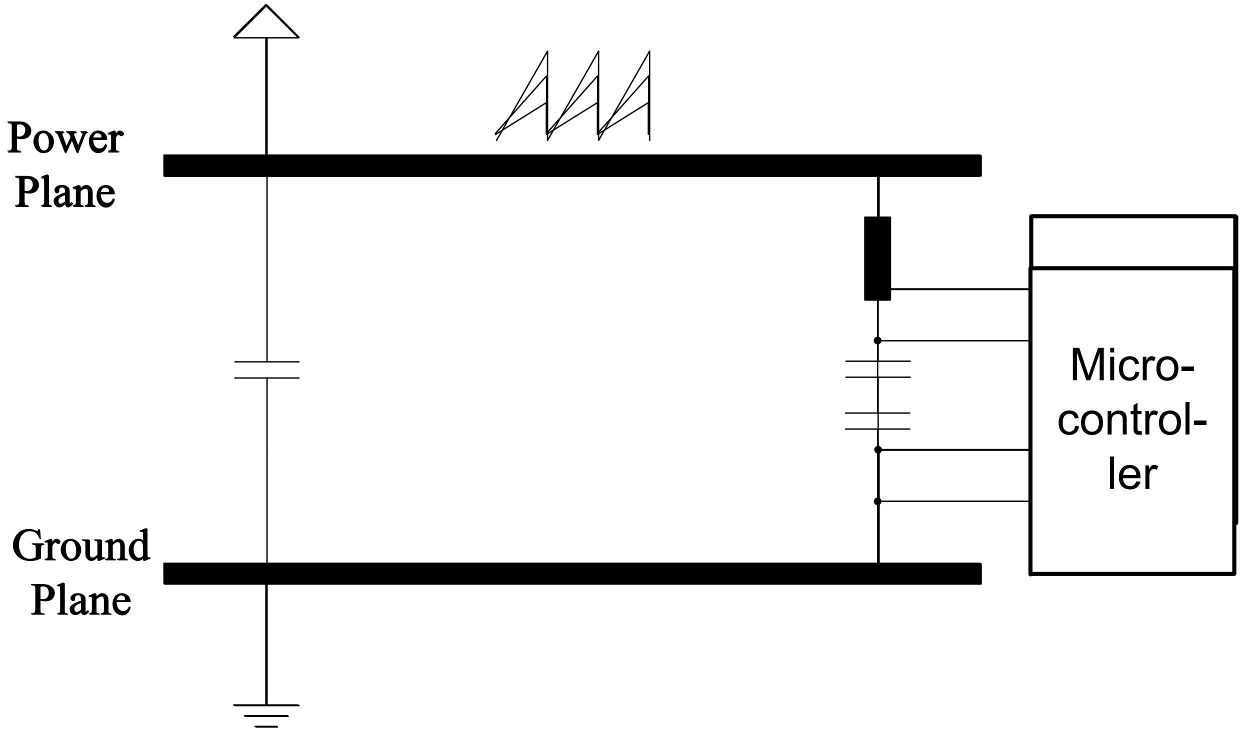
- Shield I/O connectors (or even the cables) and/or use filters for blocking noise
- Use a star-topology for ground, i.e. connect all ground lines in a common point

Shielding

- For higher frequencies a thinner shield is sufficient (e.g., conductive foil, tape, or paint)
- For higher frequencies (shorter wavelengths) the tolerable gap dimension in the shield decreases
  - Ca. 1/10 of wavelength
- Create compartments separated with vertical metal strips on the PCB

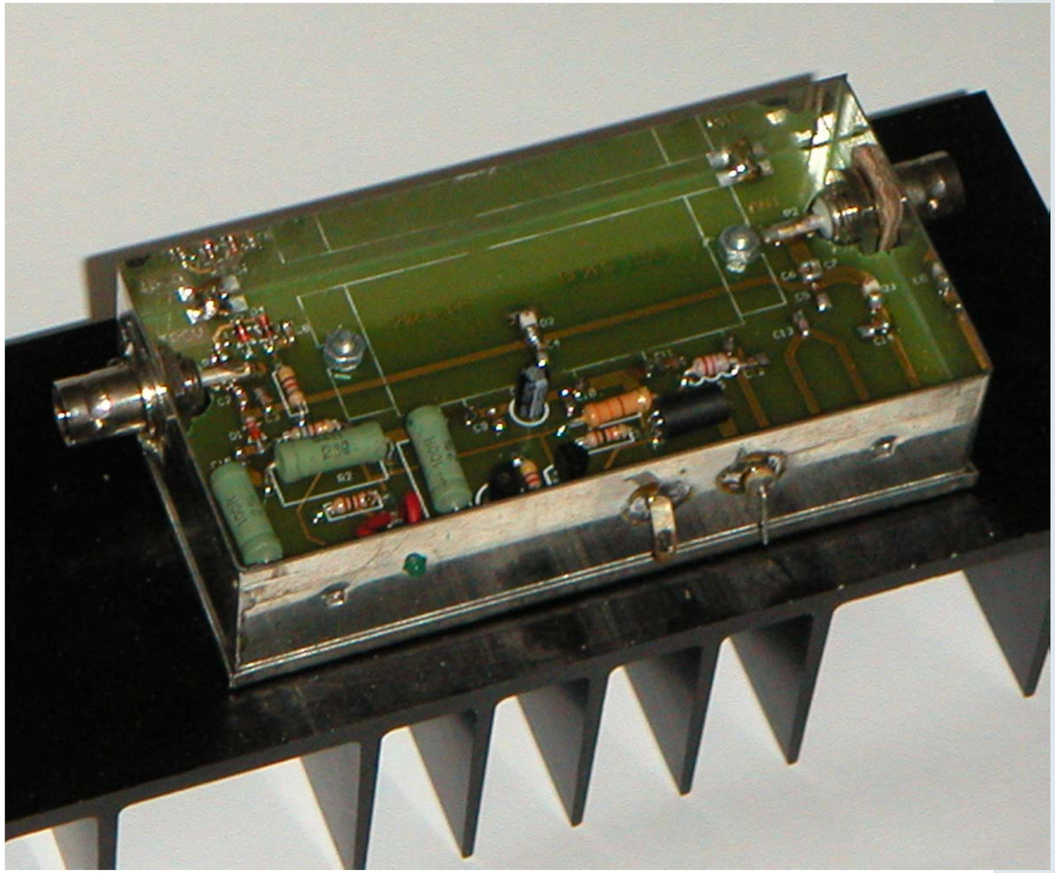
Decoupling Capacitors

“Decoupling is stopping a portion of a circuit from being affected by switching that happens in another portion.”



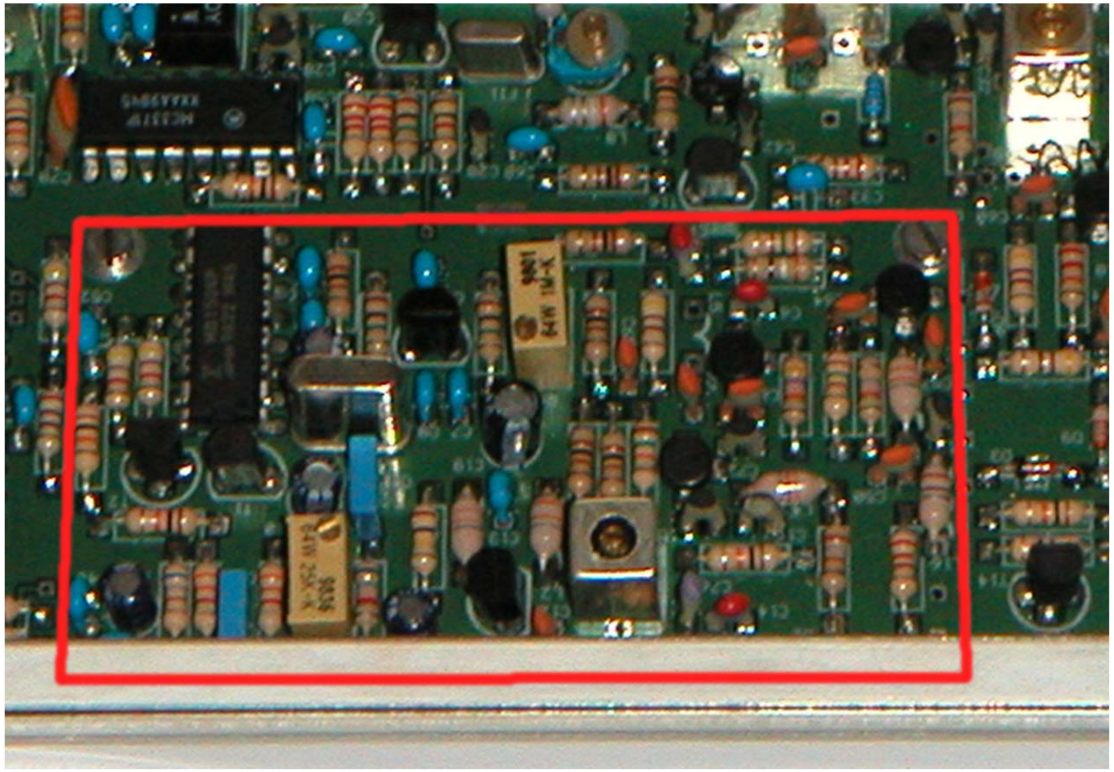
Example of a shielded circuit

- Metal case protects against undesired electro-magnetic waves
- Feed-through capacitor for decoupling the power supply



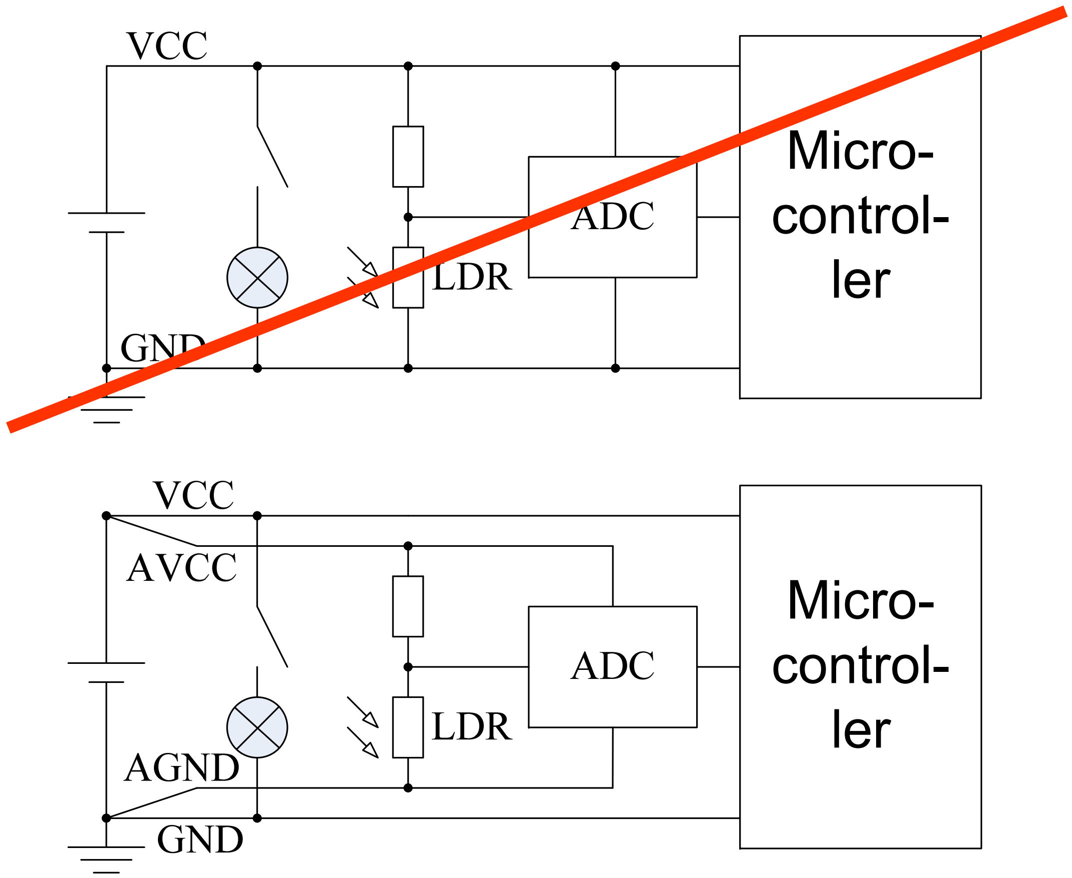
Subdivision of a system

Further shielding could be achieved with compartments of conductive material soldered on the PCB



Path to Ground

- Separate high noise/current lines and analog/sensitive signals



Things to consider for High-Current Tracks

- High currents heat up tracks on the PCB
- Warmer copper has a higher resistance
- The increased resistance causes more heat dissipation

- For high frequencies the current accumulates in the outer layers of the conductor („Skin-Effect“)
  - alternating magnetic field (due to AC) within a conductor causes eddy current
  - impedance increases

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Further References

- Eagle (http://www.cadsoft.de/)
- p-cad (http://www.pcad.com/)
- OrCAD (http://www.orcad.com/)
- PSpice (http://www.pspice.com/)
- Vendor-specific application notes
- ...

THE END

Thanks for your attention!

Real-Time Systems Group