Prototyping techniques for microelectronics laboratory

Introduction

Goal of this lecture: to learn the main prototyping techniques that will be used within the course

- How to develop simple test circuits?
- What kind of components will we use?
- What are the most common mounting techniques?
- What is a PCB?
- What is a breadboard?
- How to design a breadboard or a PCB (Fritzing)?
- How to solder electronic components?

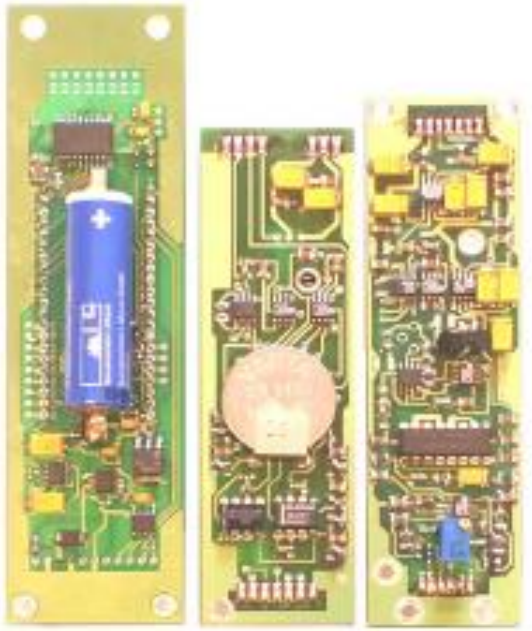
What is a PCB?

Mechanical platform providing:

- electrical interconnections of electronic components
- a surface for mounting electronic components

PCB or PWB

printed circuit board

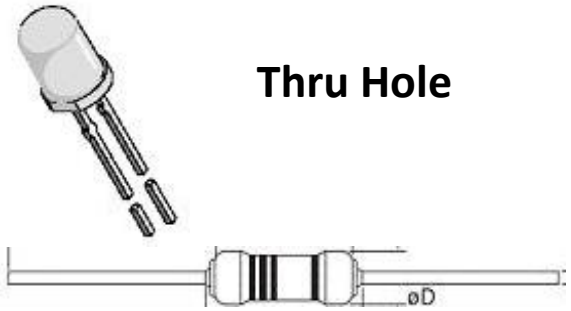


PCA

printed circuit assembly

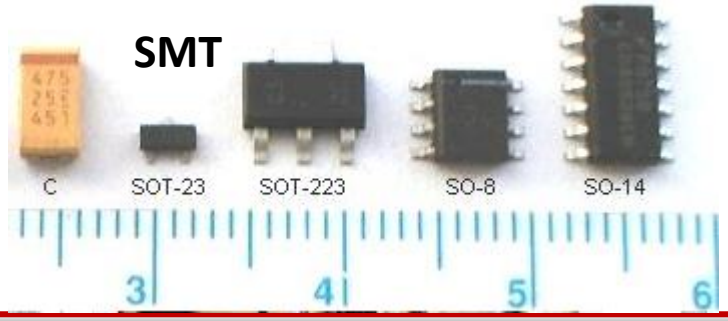
Various kinds of PCBs

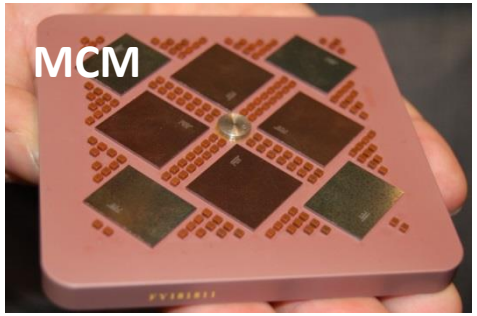
- **Printed Circuit Boards (PCBs):**
  - Convenient form of interconnecting electrical components using industry standard attachment processes
  - 3 Basic Types of PCB-Component Assembly Technology
    - Thru Hole (TH)
    - Surface Mount (SMT)
    - Micro-electronic Multi-Chip-Module (MCM)
  - 3 Basic Types of PCB substrate systems (fabs)
    - Rigid epoxy including FR4, BT and others
    - Ceramic, Alumina (Al_2O_3), AlNi, Metal core
    - Flexible Substrate (flex circuit)
  - Single, Double and Multi-Layered



Thru Hole

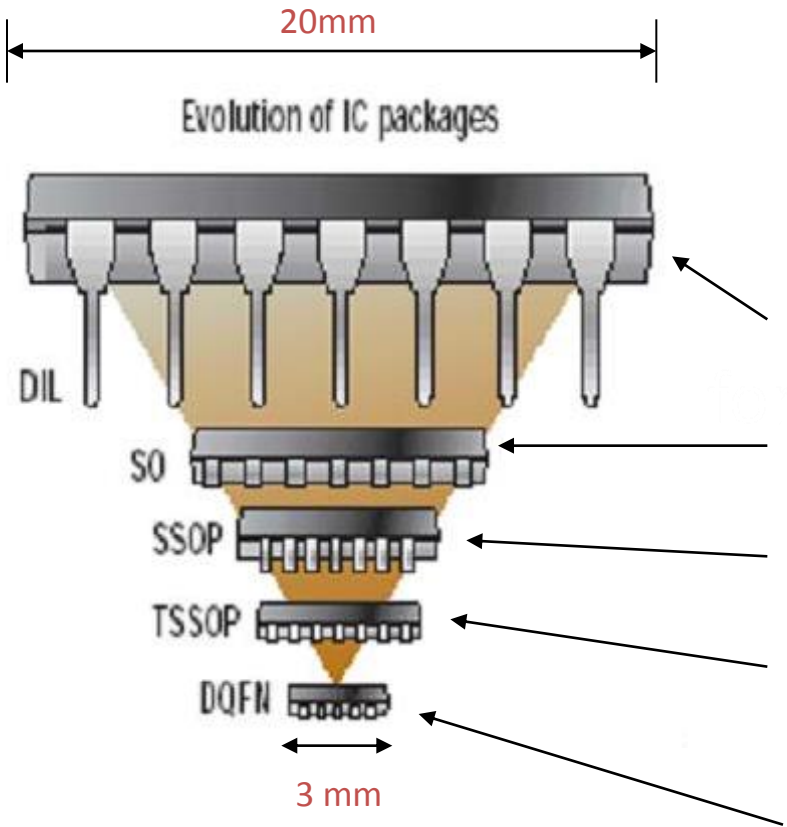
SMT





Generations of SMT devices

SMT – Surface Mount Technology Generations



DIP

Small Outline Package

Shrink SO Package

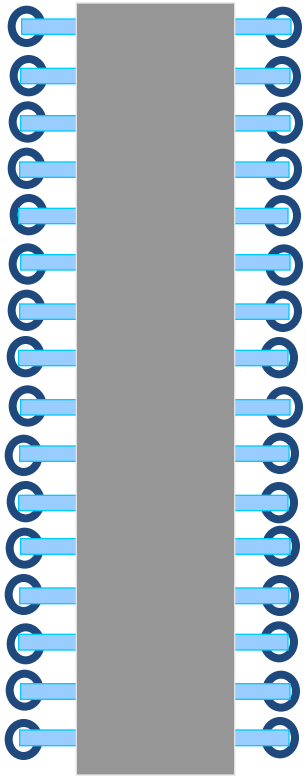
Thin Shrink SOP

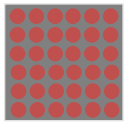
Depopulated, Very Thin, Quad Flat Pack, No Leads

IC Packaging progression

Through Hole → **Surface Mount** → **CSP / WLP**

(CSP = Chip Scale Package,
WLP = Wafer Level Package)





SOP

- Small outline package
- 25 mil pitch
- Limited by perimeter leads

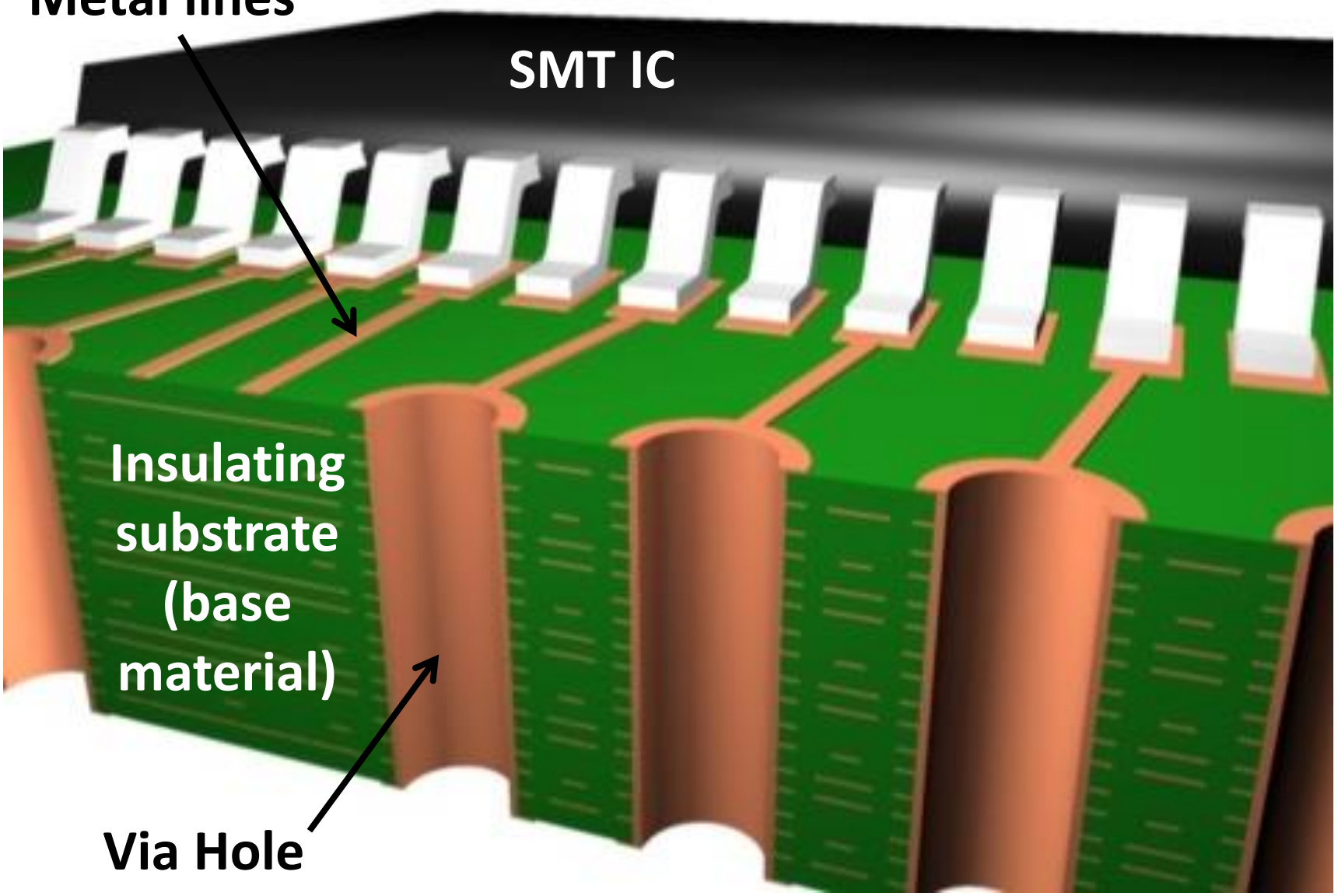
CSP/WLP

- Area array 0.8 mm to 0.5 mm
- Limited by substrate wiring

- 100 mil pitch
- Limited by through hole spacing

1 mil = 0.0254 millimeters (2.54 cm/1000=25.4 mm/1000)

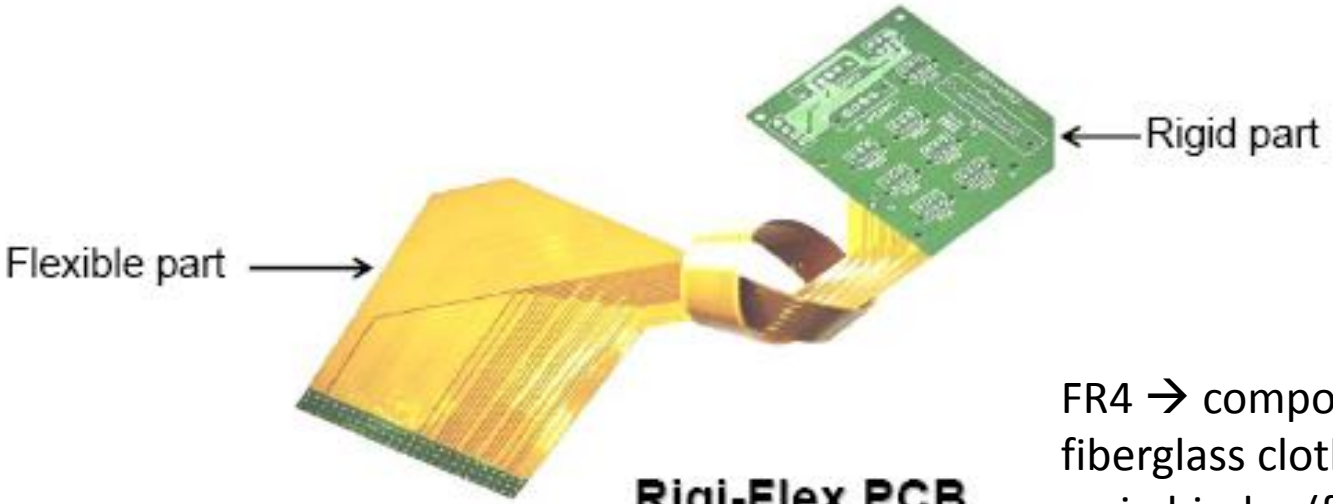
PCB: section


Metal lines
SMT IC
Insulating substrate (base material)
Via Hole

Various kinds of PCBs…

PCB-classification

Base material	Conductor pattern	Physical nature	Production method
❖Organic (FR4)	❖Discrete (no imaging)	❖Rigid (+/-)	❖Print
❖Inorganic (Ceramic)	❖Graphic (photo imaging)	❖Flexible (-)	❖Etching
		❖**Rigi-Flex (+/-)**	❖Pattern plating
			❖Laser cutting



Rigi-Flex PCB

FR4 → composite material, fiberglass cloth with an epoxy resin binder (flame resistant)

Physical characteristics

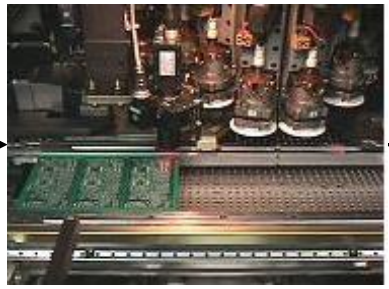
	FR4	Polyimide-Flex
Relative permittivity	4.7	3.4
Dielectric loss factor	0.021	0.002
Resistivity [Ωm]	$3x10^{11}$	10^{15}
Dielectric strength [kV/mm]	30	240
Glass transition temperature [°C]	135	220
Coefficient of thermal expansion [1/K]	$17x10^{-6}$	$25\ x10^{-6}$
E-modulus [Gpa]	25	40
Poisson's ratio	0.28	0.34
Density [kg/m^3]	1900	5560
Water absorption [%]	0.16	0.8

Typical SMT assembly process

Setup

Screen Print

SMT Placement



Reflow

Hand Assembly

Wave Solder

Final Assembly

Wash

In Circuit Test

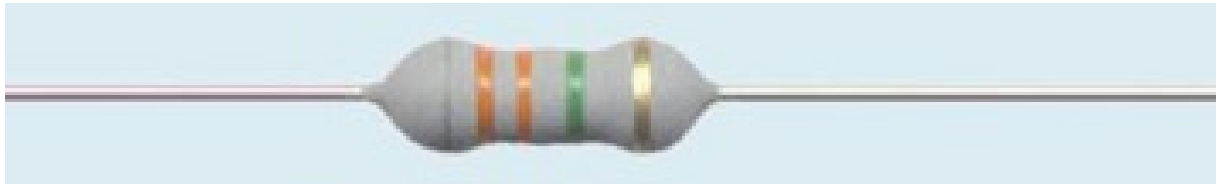
Stress Screen

Functional Test

Pack / Ship

Passive components

Standard resistor colors



- Color Code
- First 2 bands = digits
- 3d band = power of 10
- 4th band = tolerance: gold 5%, silver 10%, none 20%

- E.g. brown black red is

  = 1 0 00

  = (10 followed by 2 zeros)

	0
	1
	2
	3
	4
	5
	6
	7
	8
	9

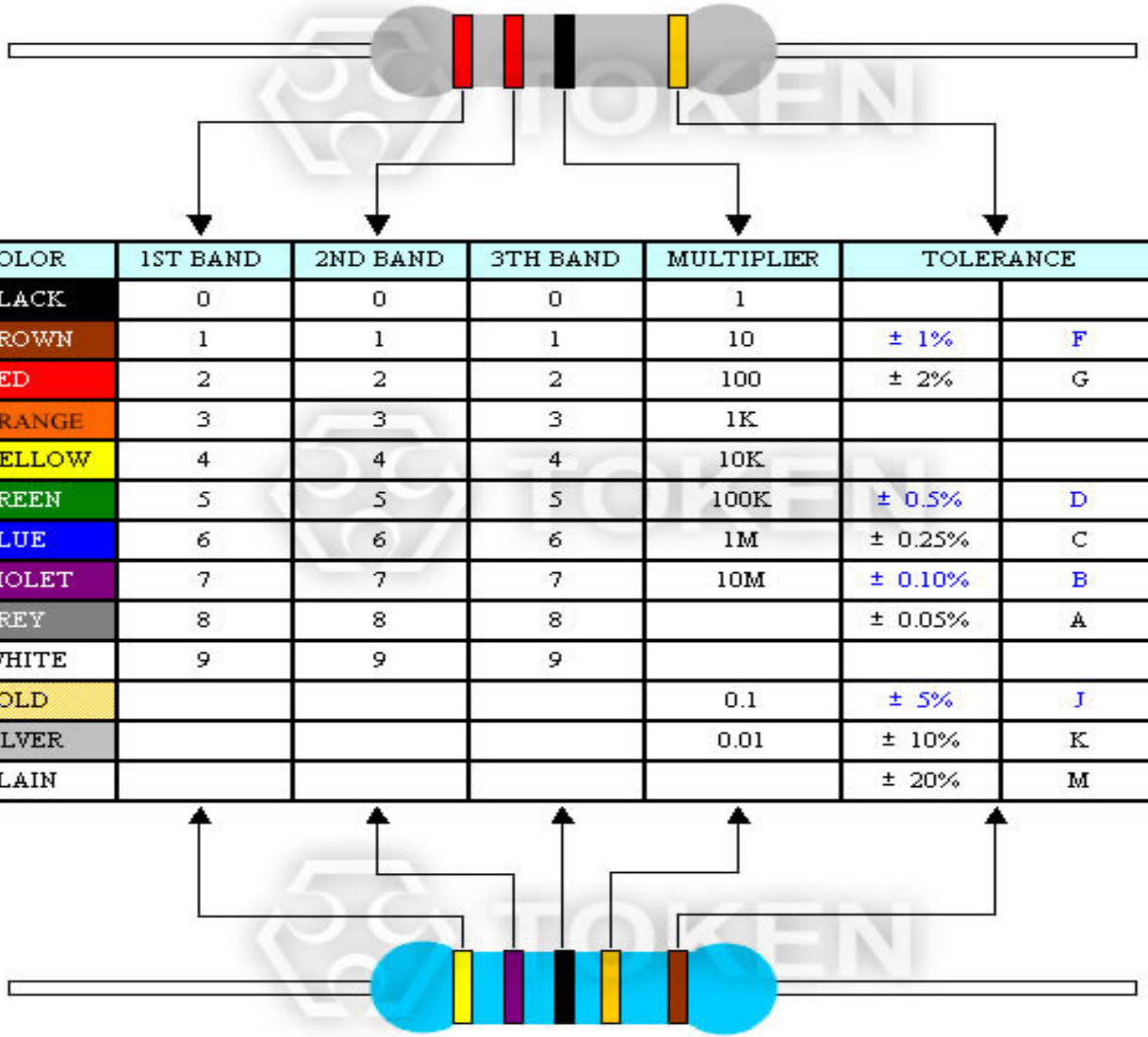
How to remember resistor colors?

- Black = 0 (no color)
- White = 9 (all colors)
- Grey is close to white, so make it 8
- Brown = ? Might as well be 1
- The rest correspond to the spectrum
  - ROYGBV

    Red = 2…etc.

Once again: the resistor color code!

TOKEN RESISTOR COLOR CODE

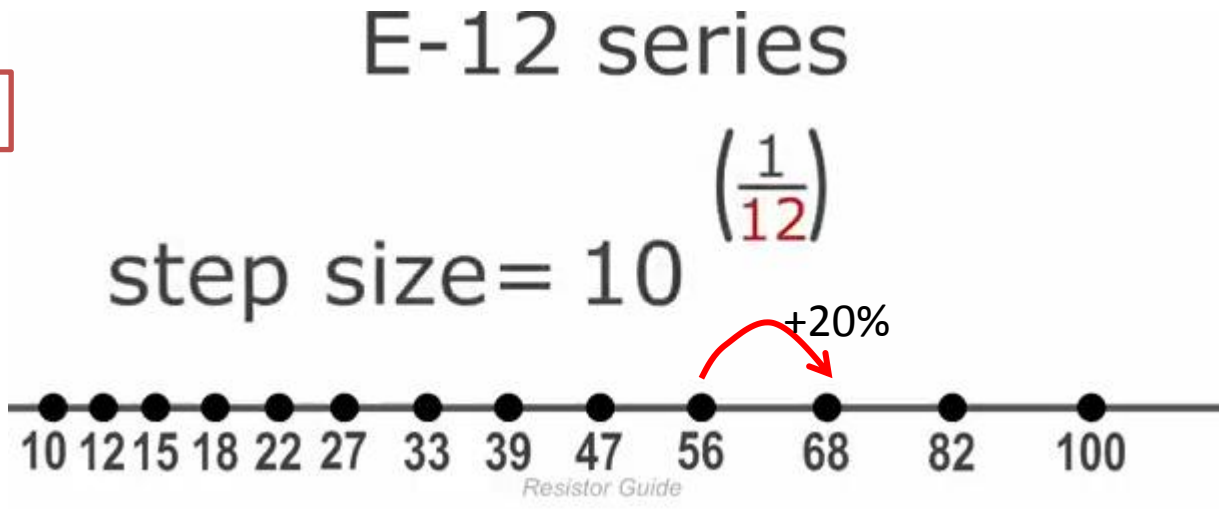


COLOR	1ST BAND	2ND BAND	3TH BAND	MULTIPLIER	TOLERANCE	
BLACK	0	0	0	1		
BROWN	1	1	1	10	± 1%	F
RED	2	2	2	100	± 2%	G
ORANGE	3	3	3	1K		
YELLOW	4	4	4	10K		
GREEN	5	5	5	100K	± 0.5%	D
BLUE	6	6	6	1M	± 0.25%	C
VIOLET	7	7	7	10M	± 0.10%	B
GREY	8	8	8		± 0.05%	A
WHITE	9	9	9			
GOLD				0.1	± 5%	J
SILVER				0.01	± 10%	K
PLAIN					± 20%	M

From http://www.token.com.tw/resistor/image/color-code.jpg

Standard resistor values: the E12 series

IEC 60063



10% tolerance

Other E-series

Other E-series...

E-6	20%	
E-12	10%	
E-24	5%	
E-48	2%	
E-96	1%	3 digits
E-192	0.5-0.25-0.1%	

Types of capacitors

Ceramic capacitors: a ceramic material is used as the dielectric; two or more layers of ceramic and metal layers (electrodes) → **They are fabricated by coating a ceramic disc with silver contacts on both sides**

Ceramic types of capacitors generally have a 3-digit code printed onto their body to identify their capacitance value in pico-farads. **Generally the first two digits indicate the capacitors value and the third digit indicates the number of zero's to be added.** For example, a ceramic disc capacitor with the markings 103 would indicate 10 and 3 zero's in pico-farads which is equivalent to 10,000 pF or 10nF.

Ceramic Capacitor

Ceramic materials for class 1 ceramic capacitors

Chemical-formula	Relative permittivity ε	Temperature-coefficient α 10^{-6}/K
$MgNb_2O_6$	21	−70
$ZnNb_2O_6$	25	−56
$MgTa_2O_6$	28	18
$ZnTa_2O_6$	38	9
$(ZnMg)TiO_3$	32	5
$(ZrSn)TiO_4$	37	0
$Ba_2Ti_9O_{20}$	40	2

http://en.wikipedia.org/

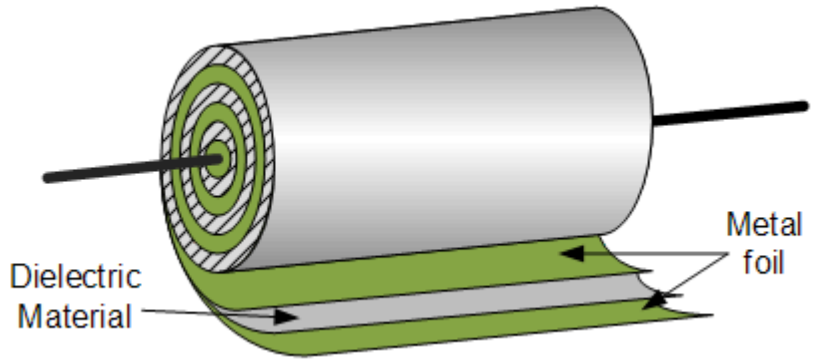
Small and cheap, often used as decoupling caps (from audio to RF)

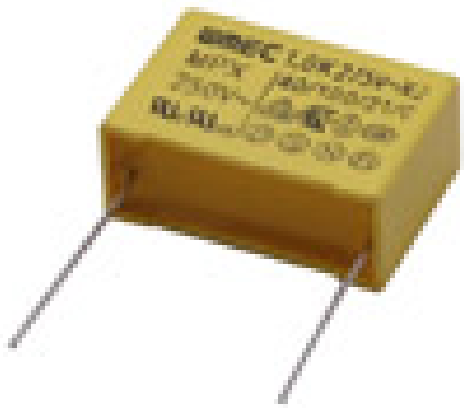
Types of capacitors

Film Capacitors → Insulating film as a dielectric → These include polyester (Mylar), polystyrene, polypropylene, polycarbonate, metalised paper, Teflon etc.

Film type capacitors are available in **capacitance ranges from as small as 5pF to as large as 100uF** depending upon the actual type of capacitor and its voltage rating. Film capacitors also come in an assortment of shapes and case styles

The electrodes → **aluminum or zinc**, which can be directly applied to the surface of the film, or be in a separate metallic foil





Low tolerance, good reliability, high temps are possible

Types of capacitors

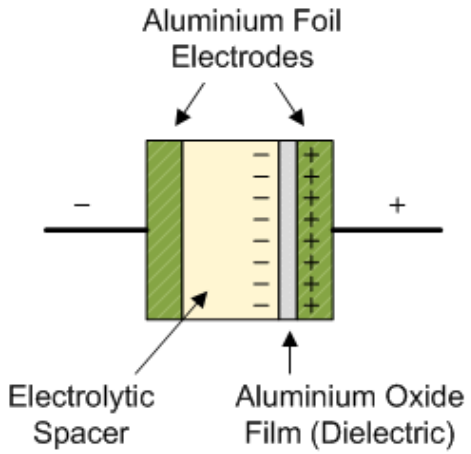
Electrolytic Capacitors are generally used when very **large capacitance values are required** (low cost and small size) → Low frequency, power supplies, decoupling…

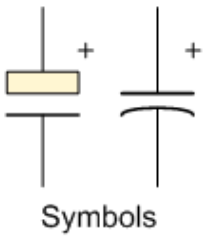
Structure:

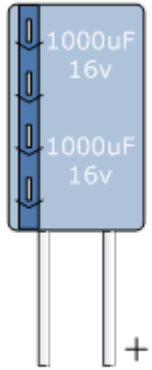
1. metal, on which an oxide forms (the oxide is the dielectric)
2. An electrolyte covers the surface of the oxide → second electrode

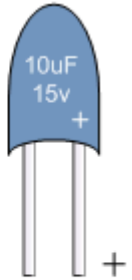
The majority of electrolytic types of capacitors are polarised, that is the DC voltage applied to the capacitor terminals must be of the correct polarity, i.e. positive to the positive terminal and negative to the negative terminal as an incorrect polarisation will break down the insulating oxide layer and permanent damage may result.

Typical use: filters and charge accumulations in supplies

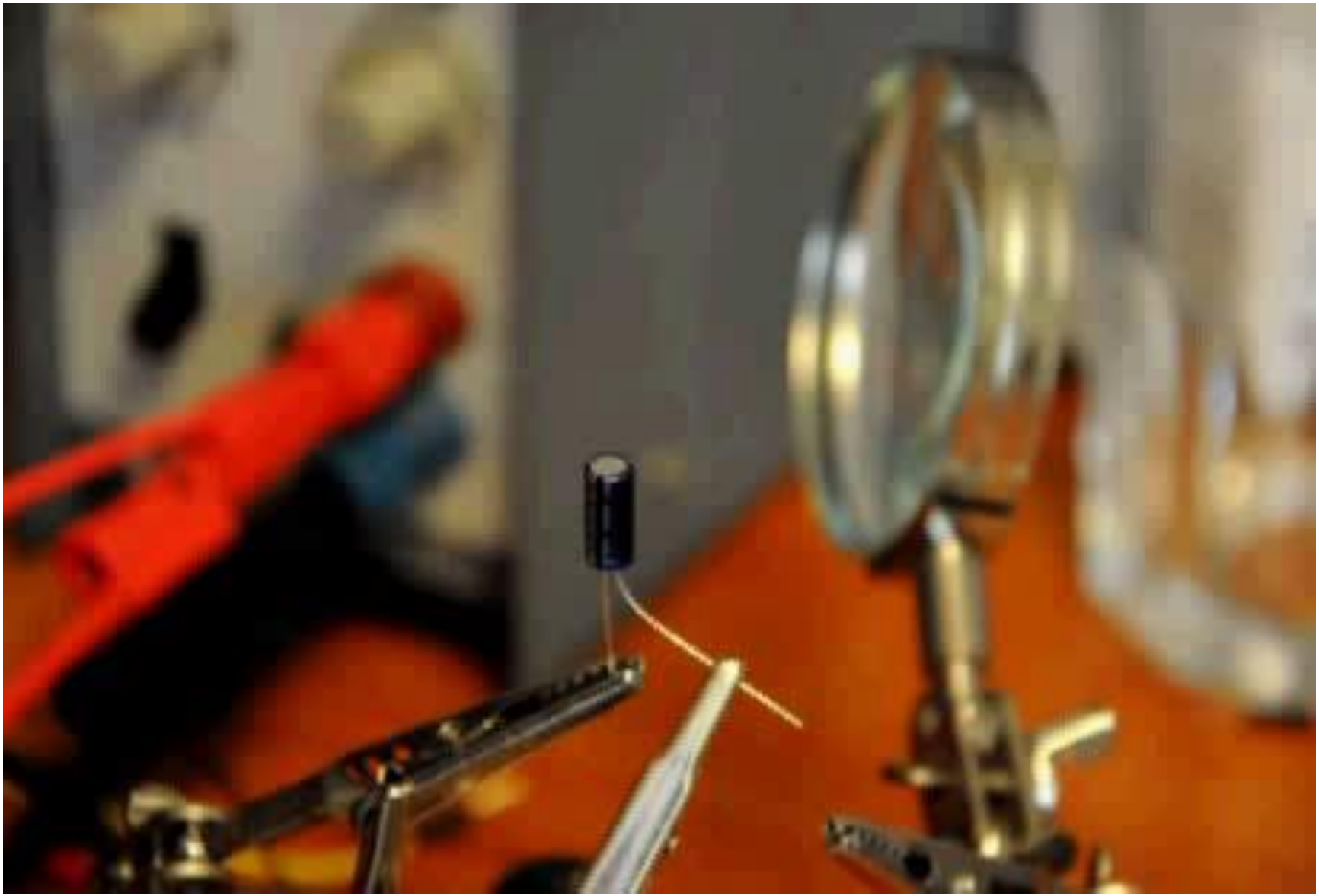




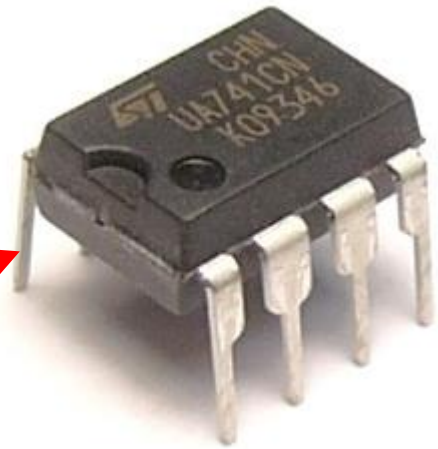


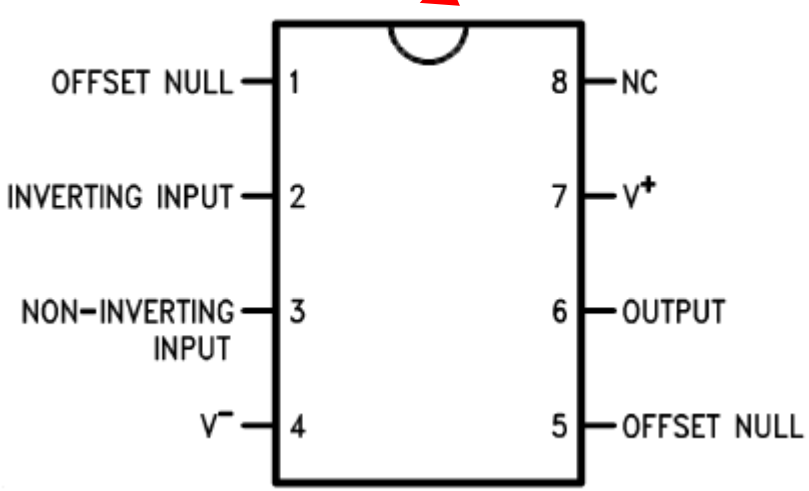


Do not mess with electrolytic capacitors!!!



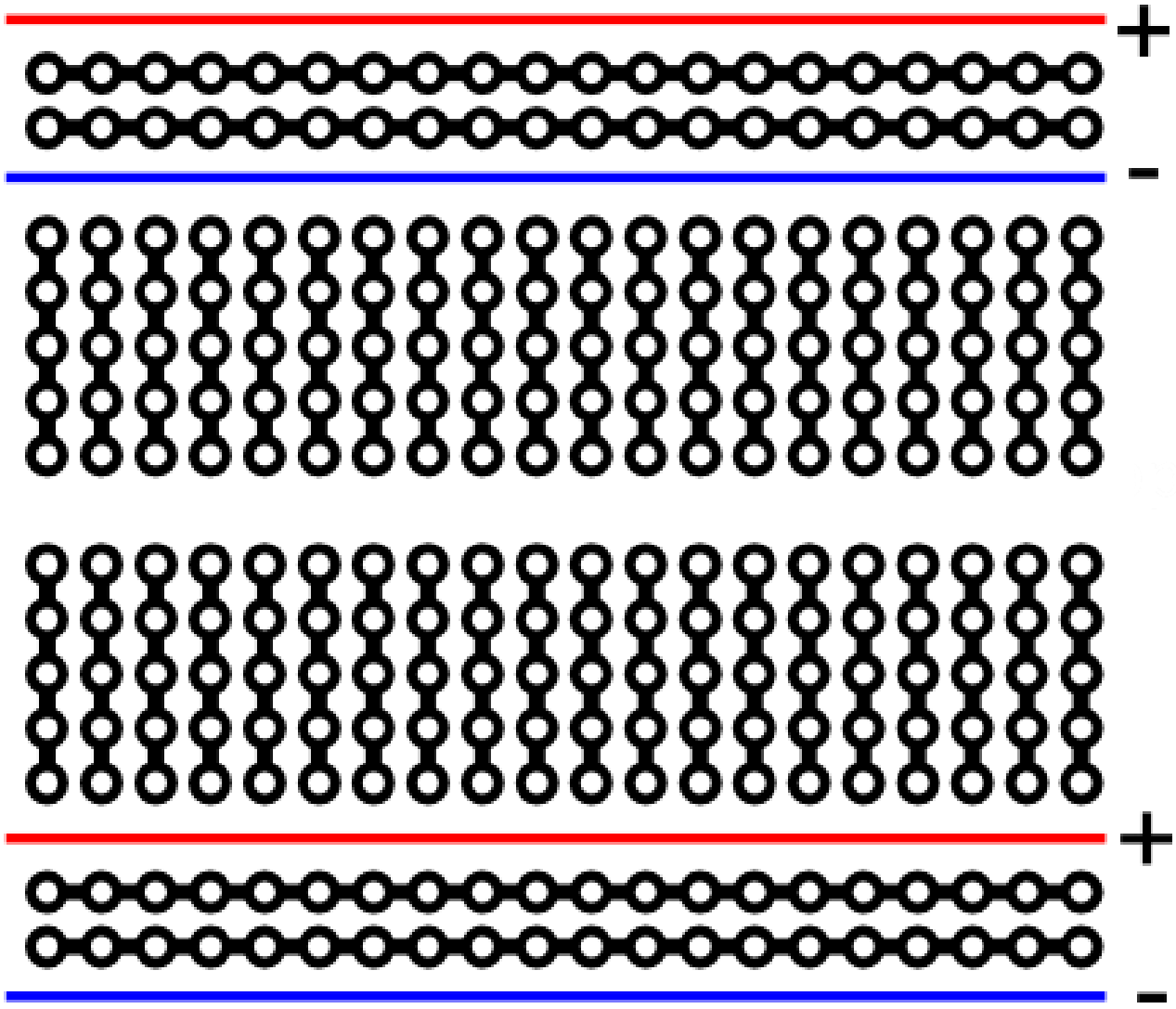
IC with DIP package





Be very careful with electrical connections!

The breadboard



The breadboard will be your buddy in the lab: it will help you creating, organizing, and prototyping circuits

Advantages:

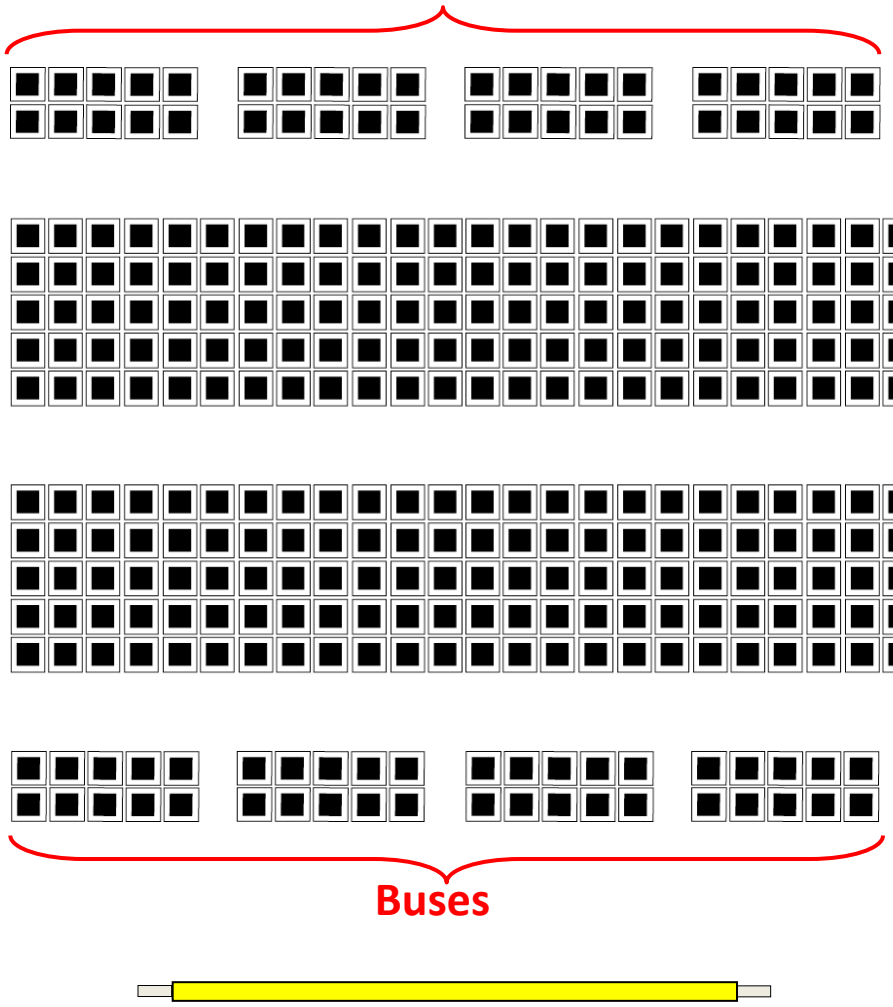
-quick mounting
-easy debugging
-easy to add/remove components

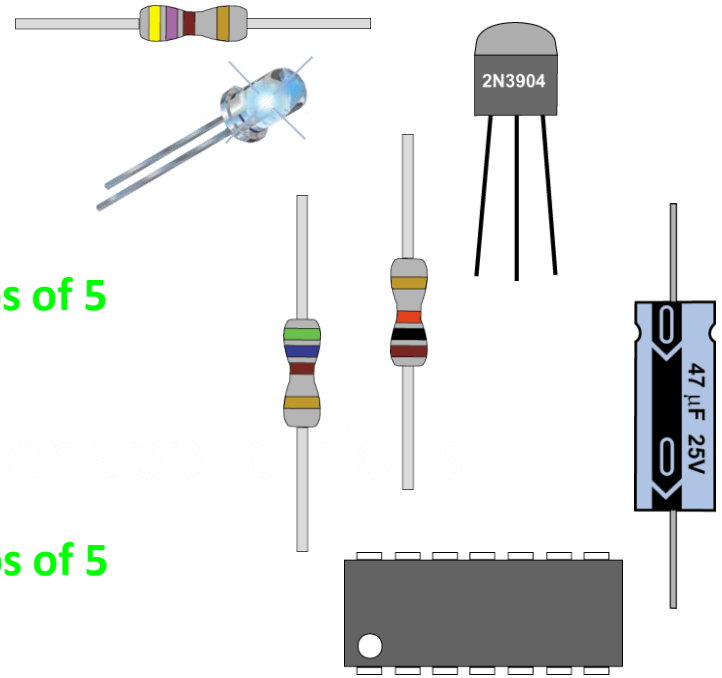
Cons:

-only good for lab tests, not for real life operation!

Breadboard

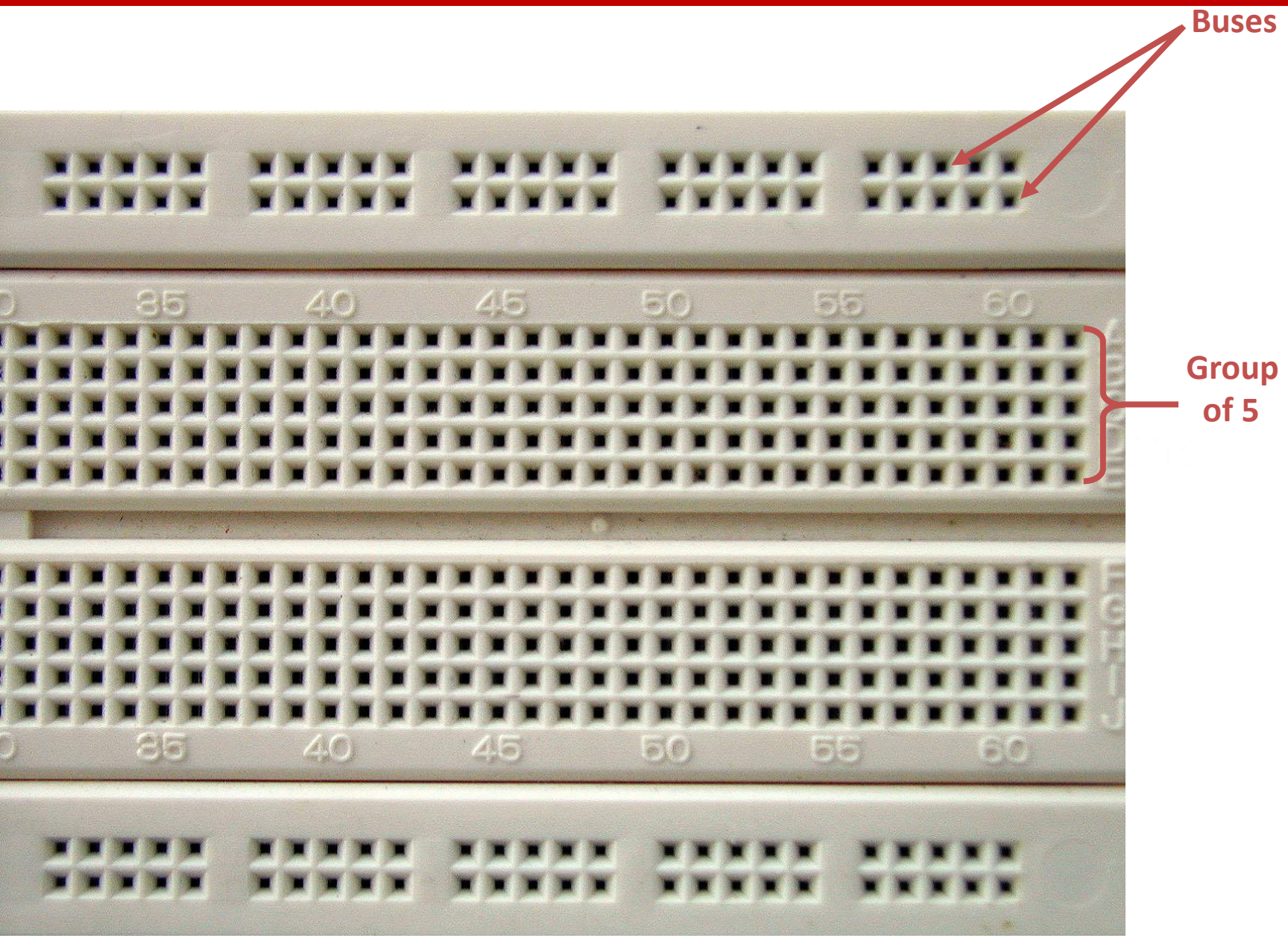
Four separate buses and 48 separate groups of 5 are shown here.



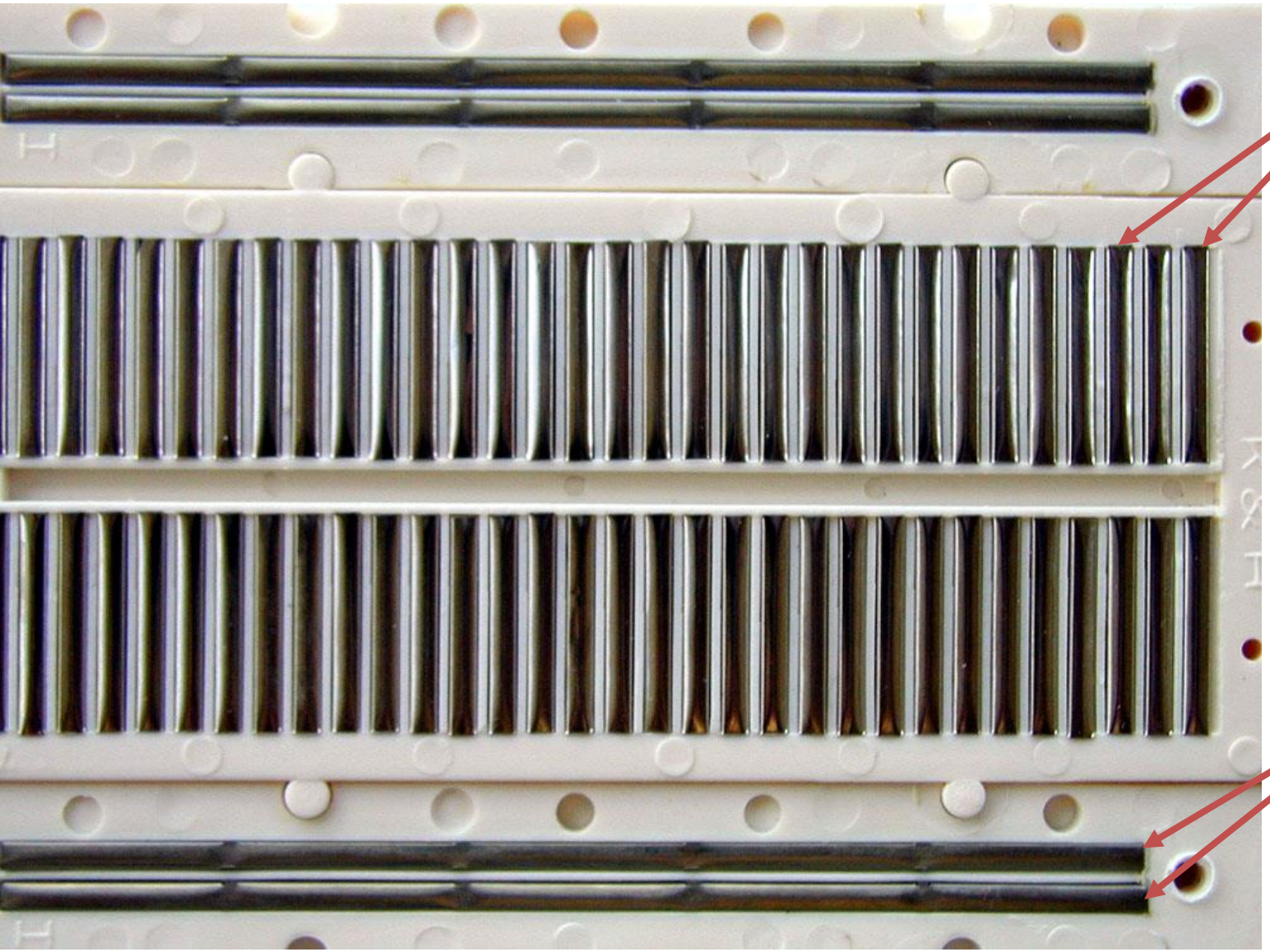


Many components have compatible leads.

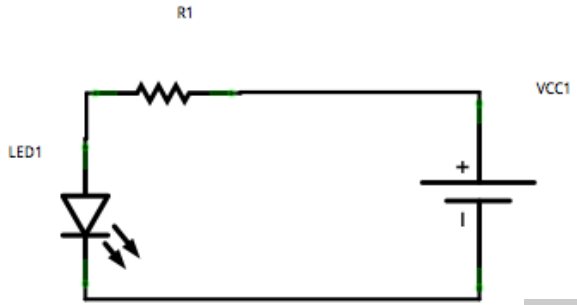
Front side of a breadboard

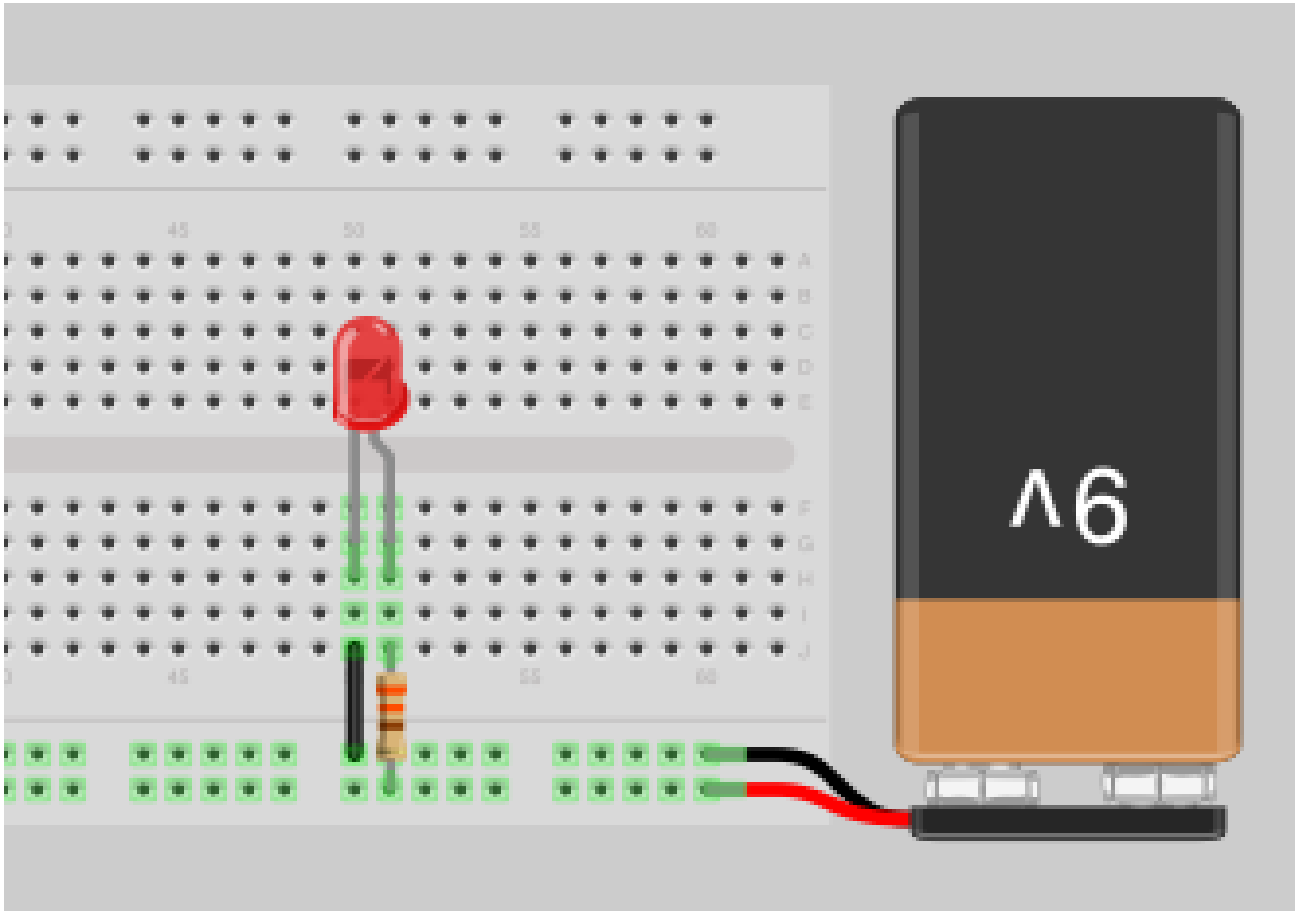


Back side of a breadboard

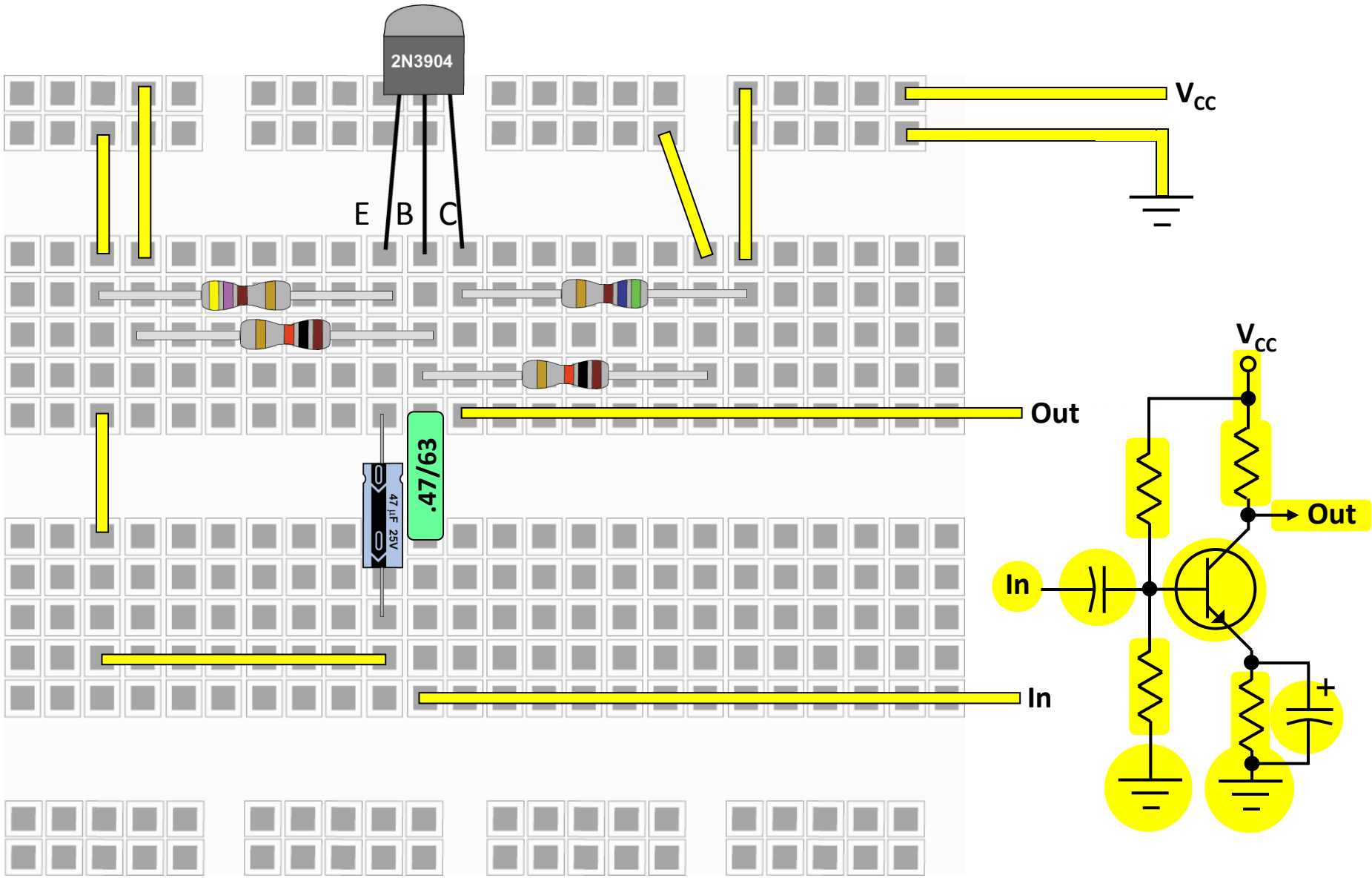


Breadboard: a very simple circuit

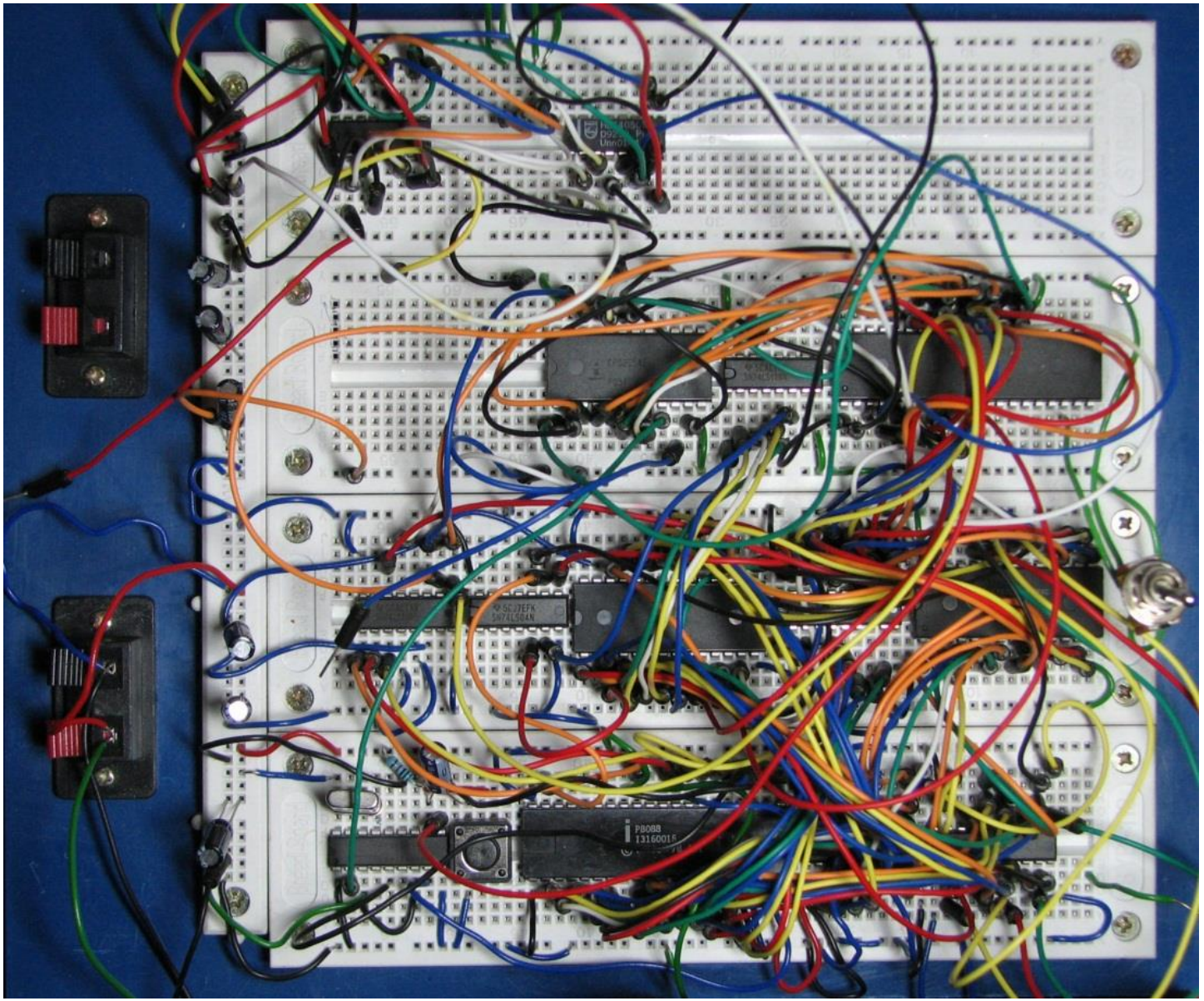




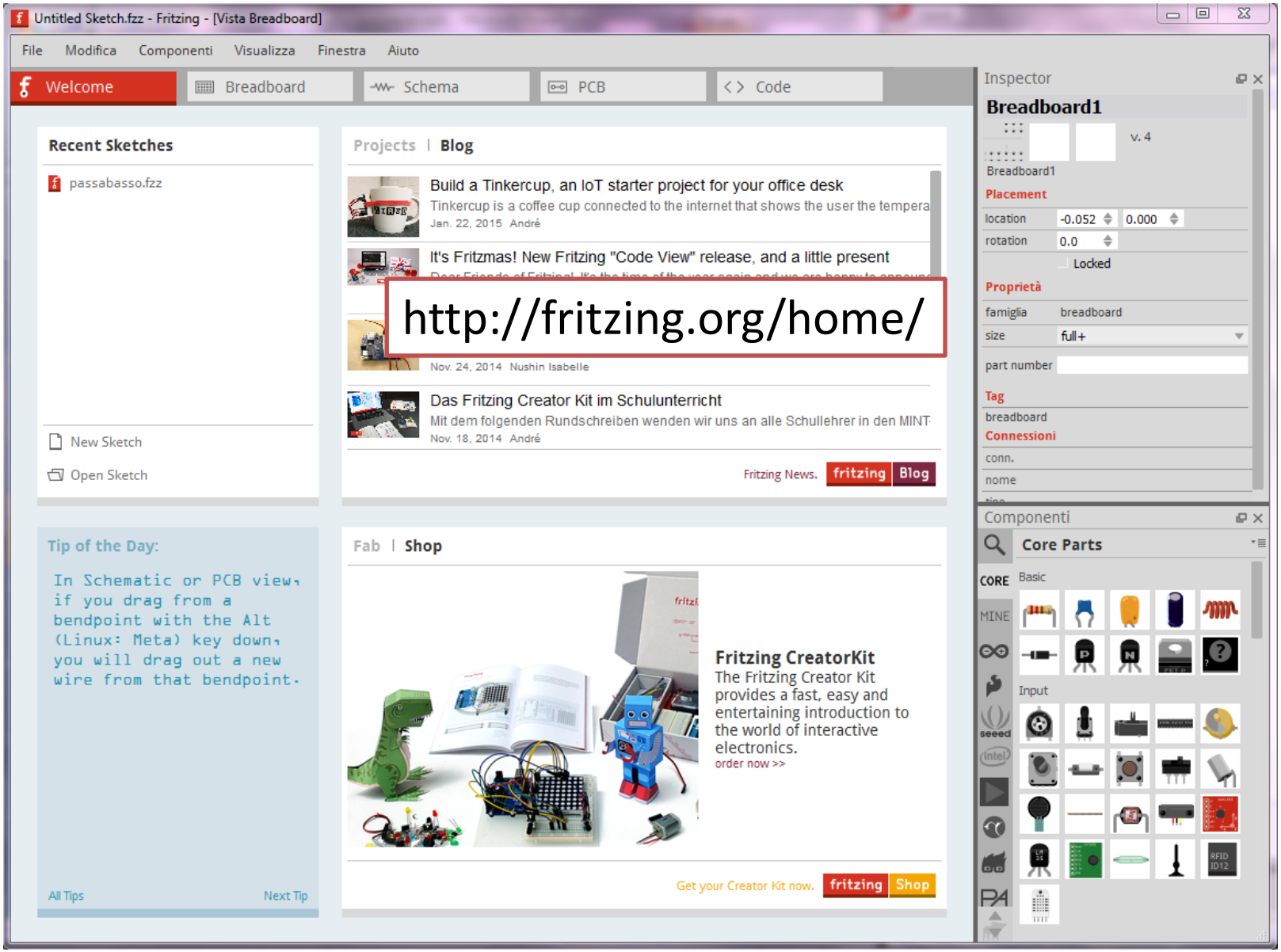
Breadboarding a transistor amplifier



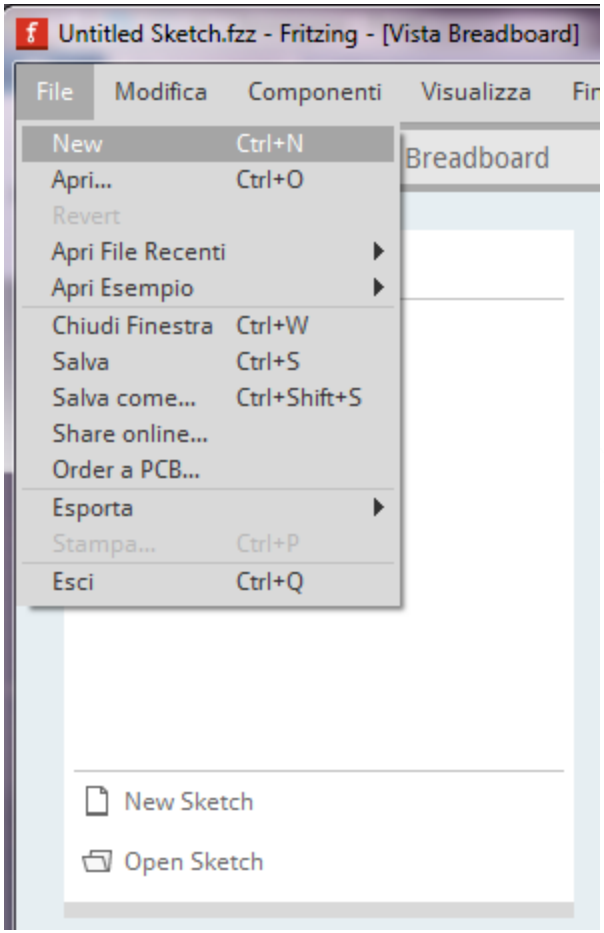
Drawbacks of Breadboards…



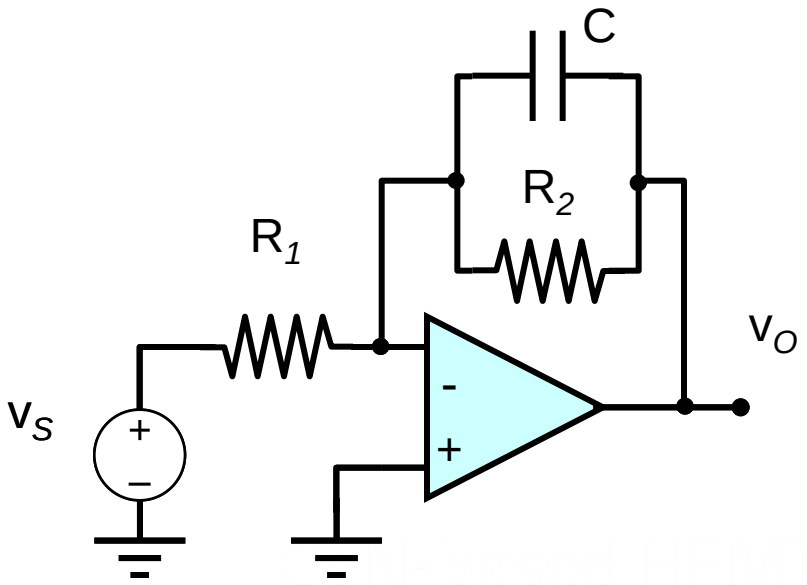
How to…organize circuits on breadboard with Fritzing



How to…organize circuits on breadboard with Fritzing



Design of a simple low pass filter



$$Z_2 = \frac{R_2 \cdot \frac{1}{sC}}{R_2 + \frac{1}{sC}} = \frac{R_2}{1 + sCR_2}$$

$$W(s) = -\frac{Z_2}{Z_1} = -\frac{R_2}{R_1} \cdot \frac{1}{1 + sCR_2}$$

$$W_{PB}(s) = \frac{A_0 \omega_H}{s + \omega_H} = \frac{A_0}{1 + \frac{s}{\omega_H}}$$

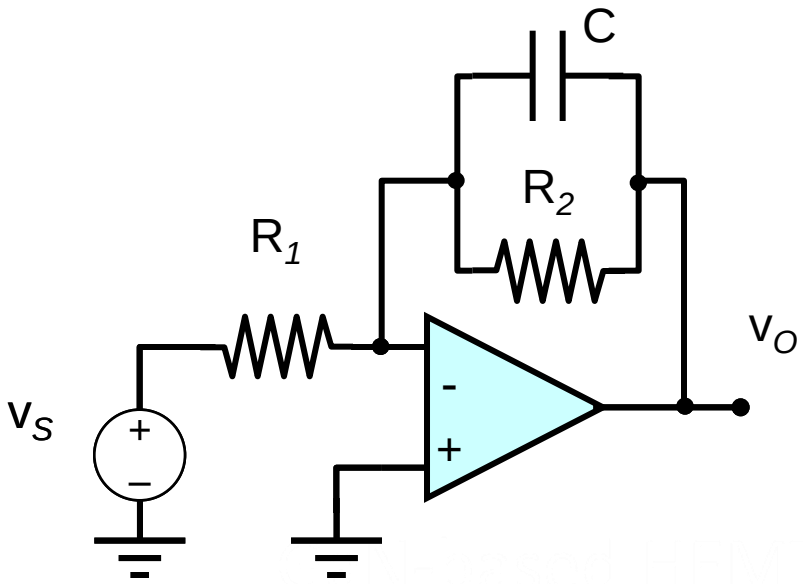
$$A_0 = -\frac{R_2}{R_1}$$

$$\omega_H = \frac{1}{R_2 C}$$

Transfer function of a low pass filter

A_0=Low frequency gain
ω_H=Bandwith

Design of a simple low pass filter



$$W_{PB}(s) = \frac{A_0 \omega_H}{s + \omega_H} = \frac{A_0}{1 + \frac{s}{\omega_H}}$$

$$A_0 = -\frac{R_2}{R_1} \qquad \omega_H = \frac{1}{R_2 C}$$

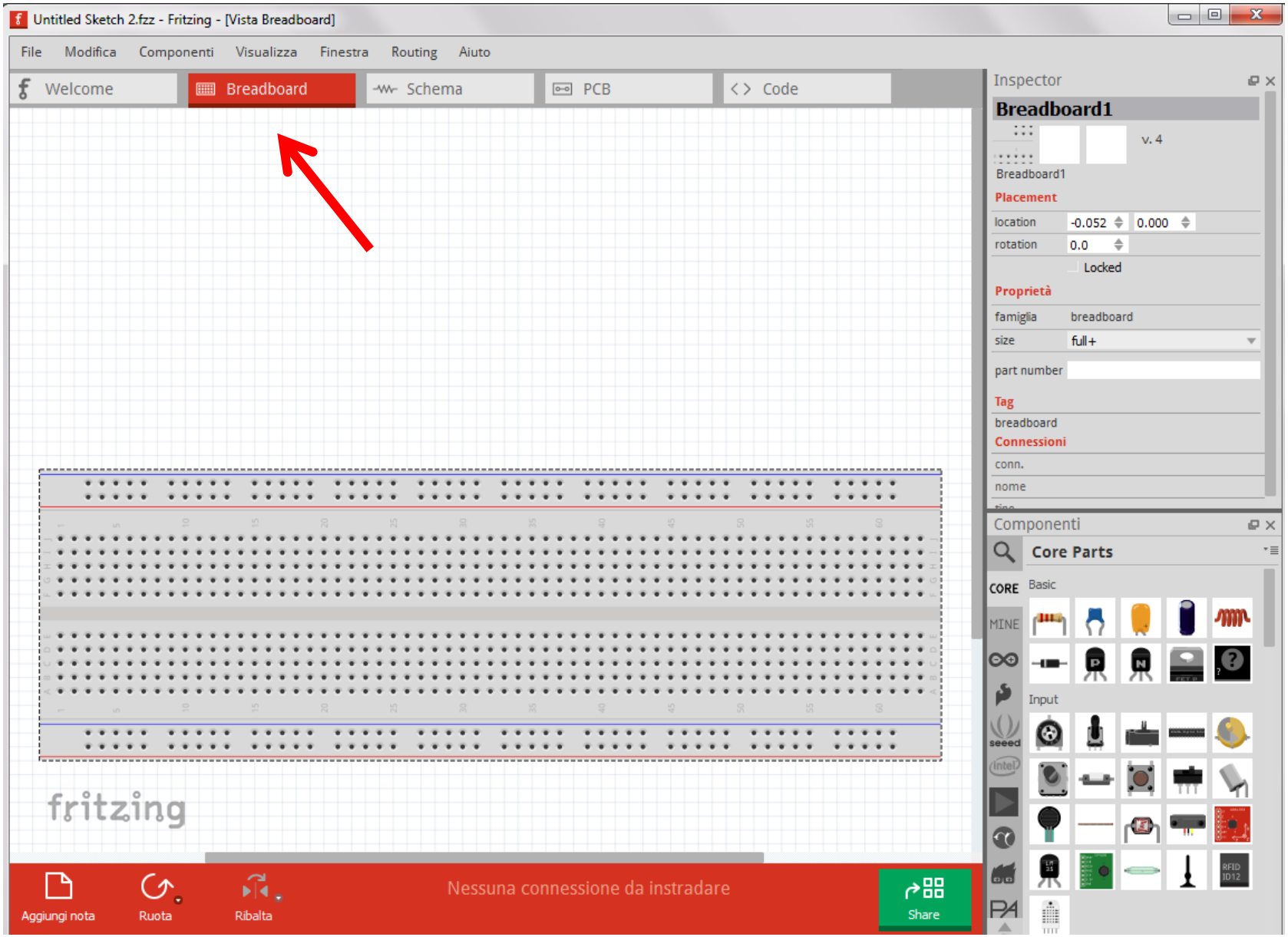
We design the filter to have: A_0=-10, $f_H=\omega_H/2\pi=1/(2\pi R_2 C)$=1000 Hz

R_2=10 R_1, $C=1/(2000\pi R_2)$

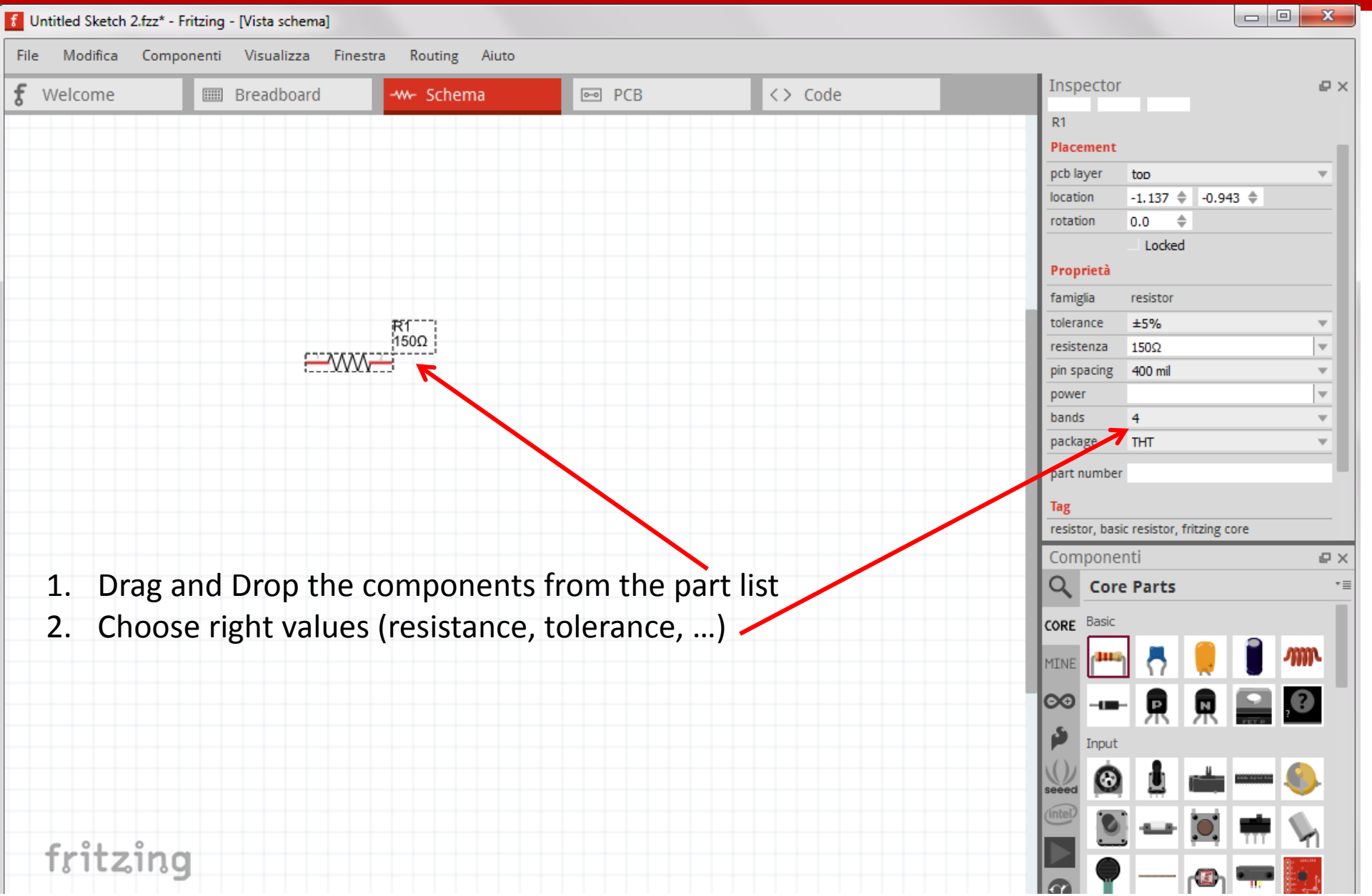
We choose:

R_1=150 Ω
R_2=1500 Ω
C=100 nF

The Breadboard Environment

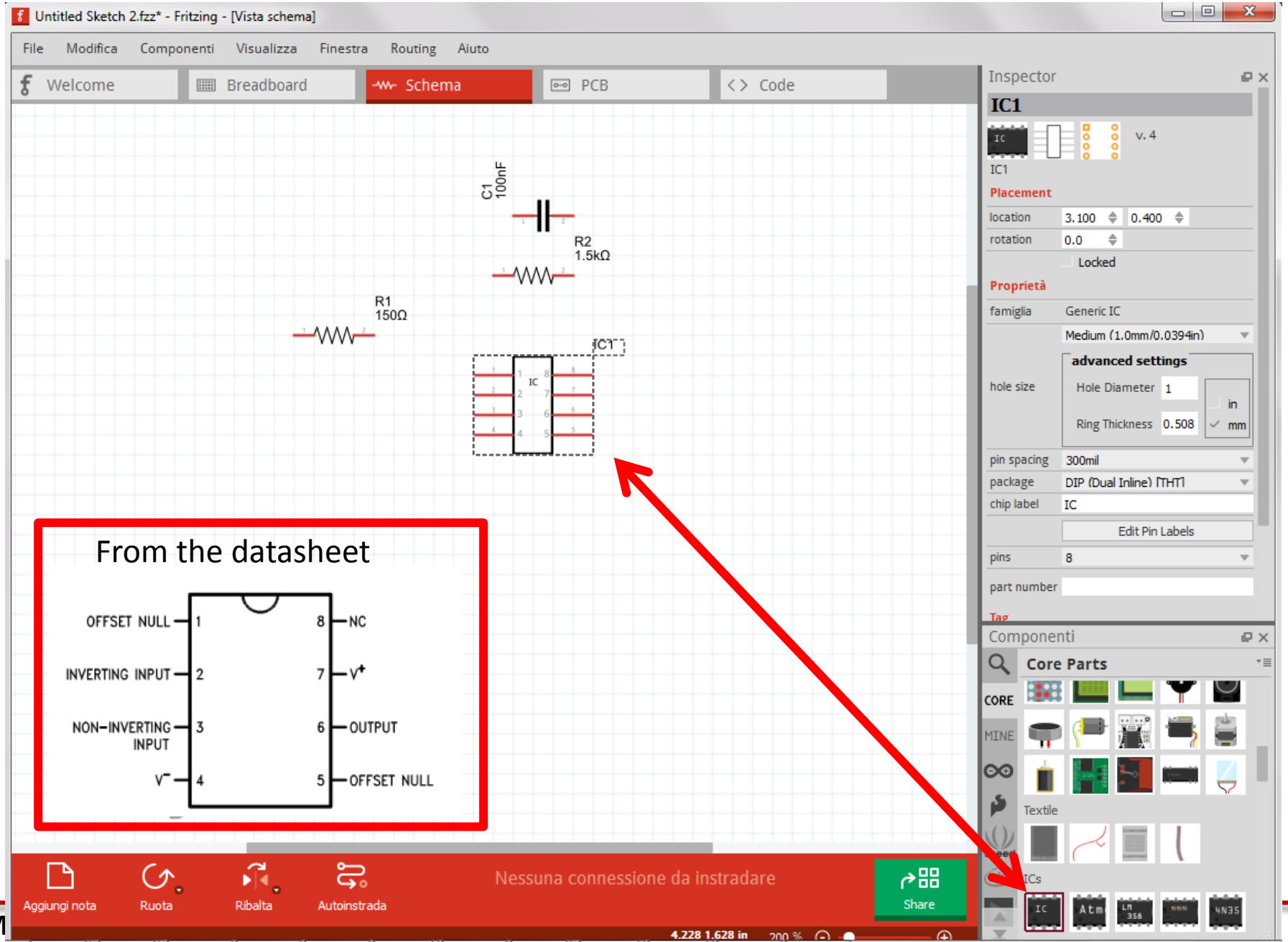


The Circuit Environment

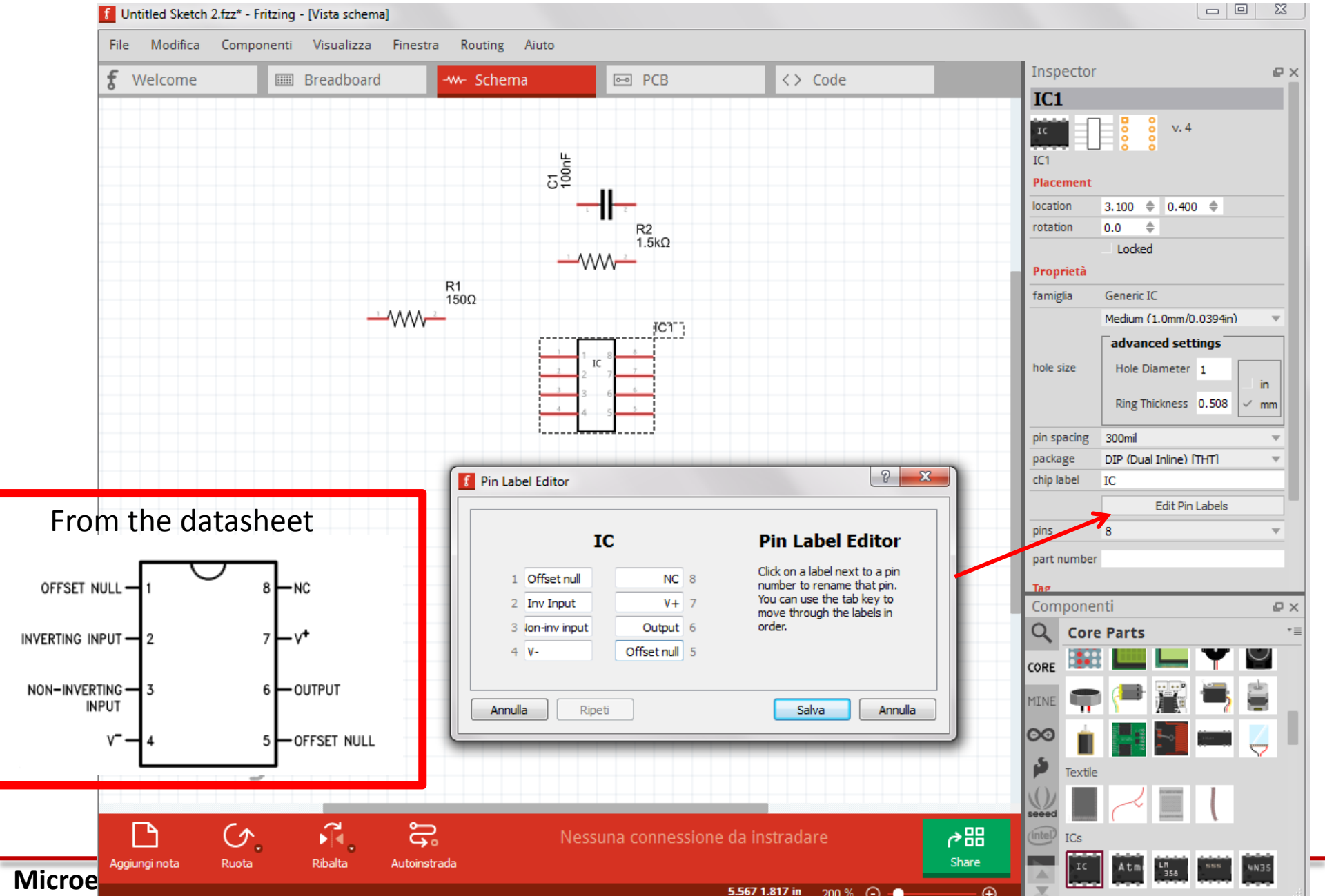


1. Drag and Drop the components from the part list
2. Choose right values (resistance, tolerance, …)

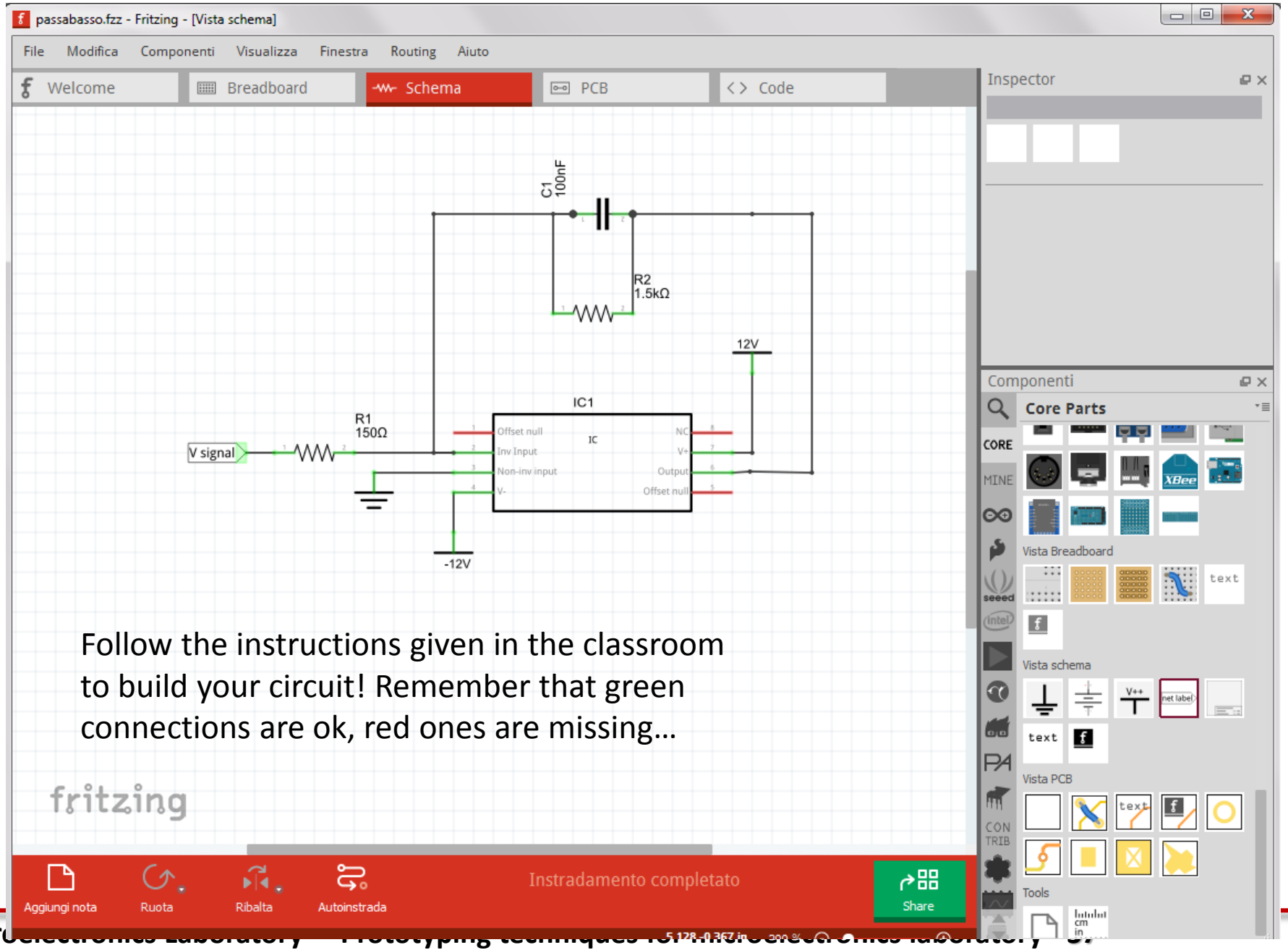
Add a generic IC from the part list



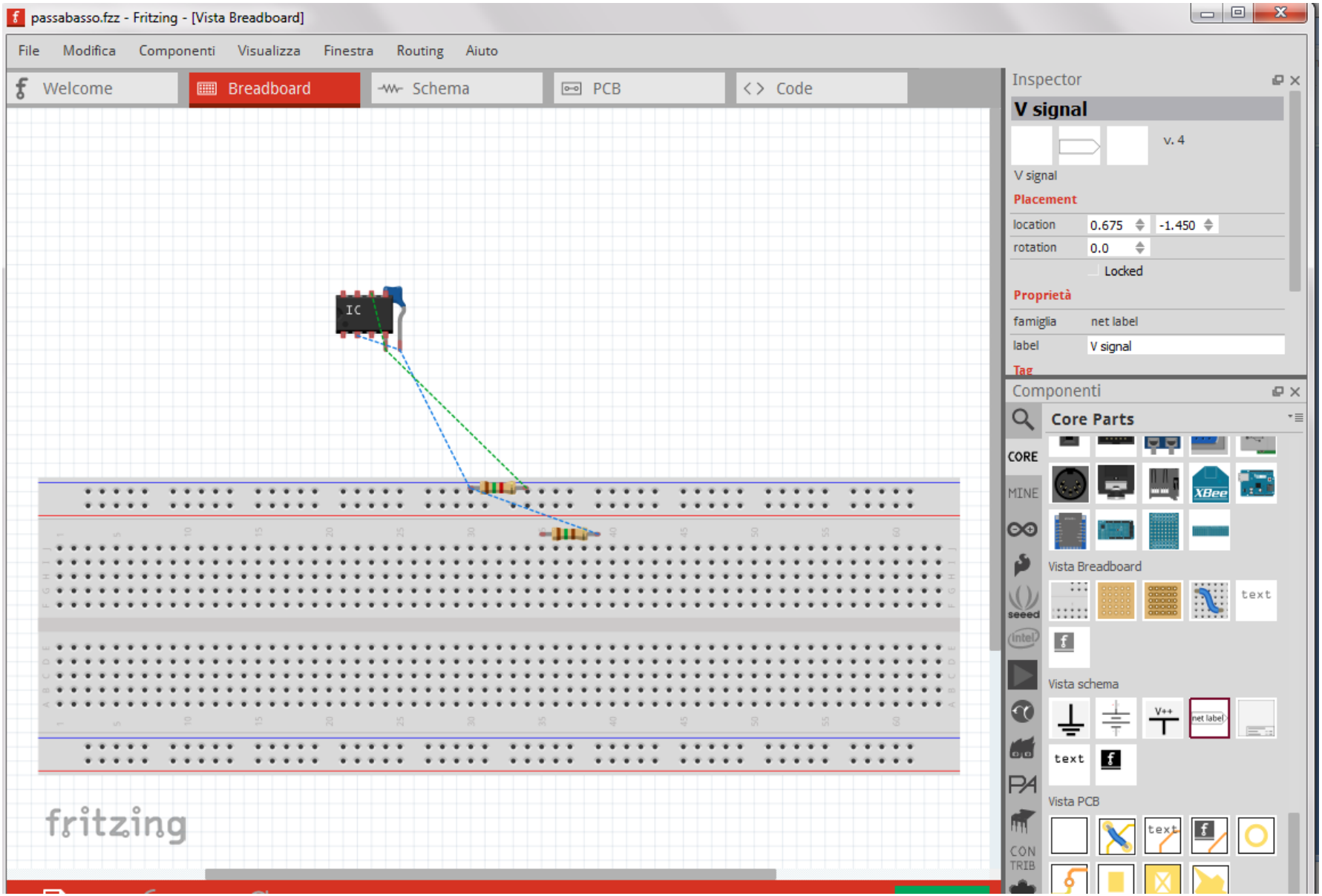
Add a generic IC from the part list



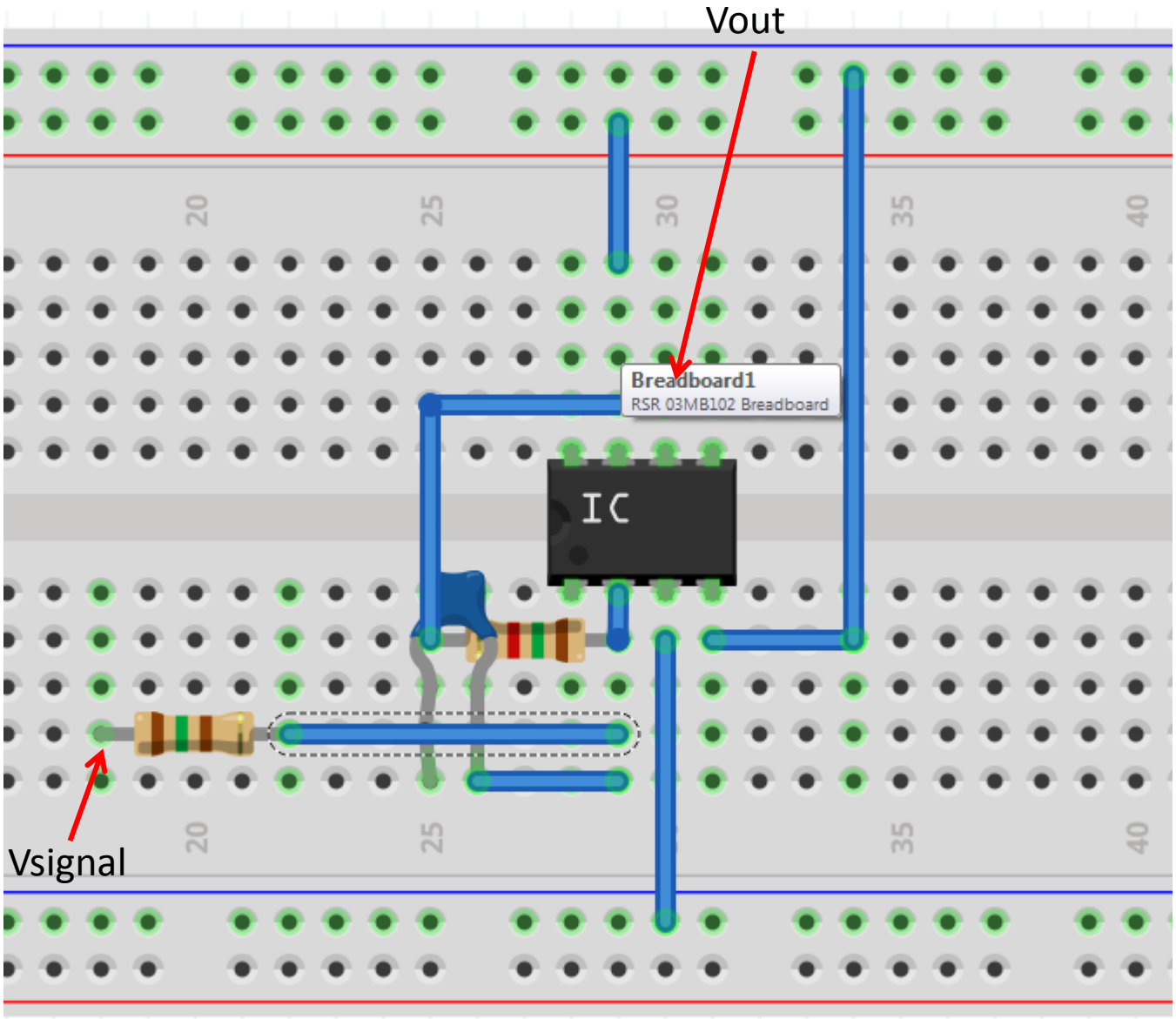
Make the electrical connections



Now…switch to the breadboard view!



Fix all the connections: use the Rastnet

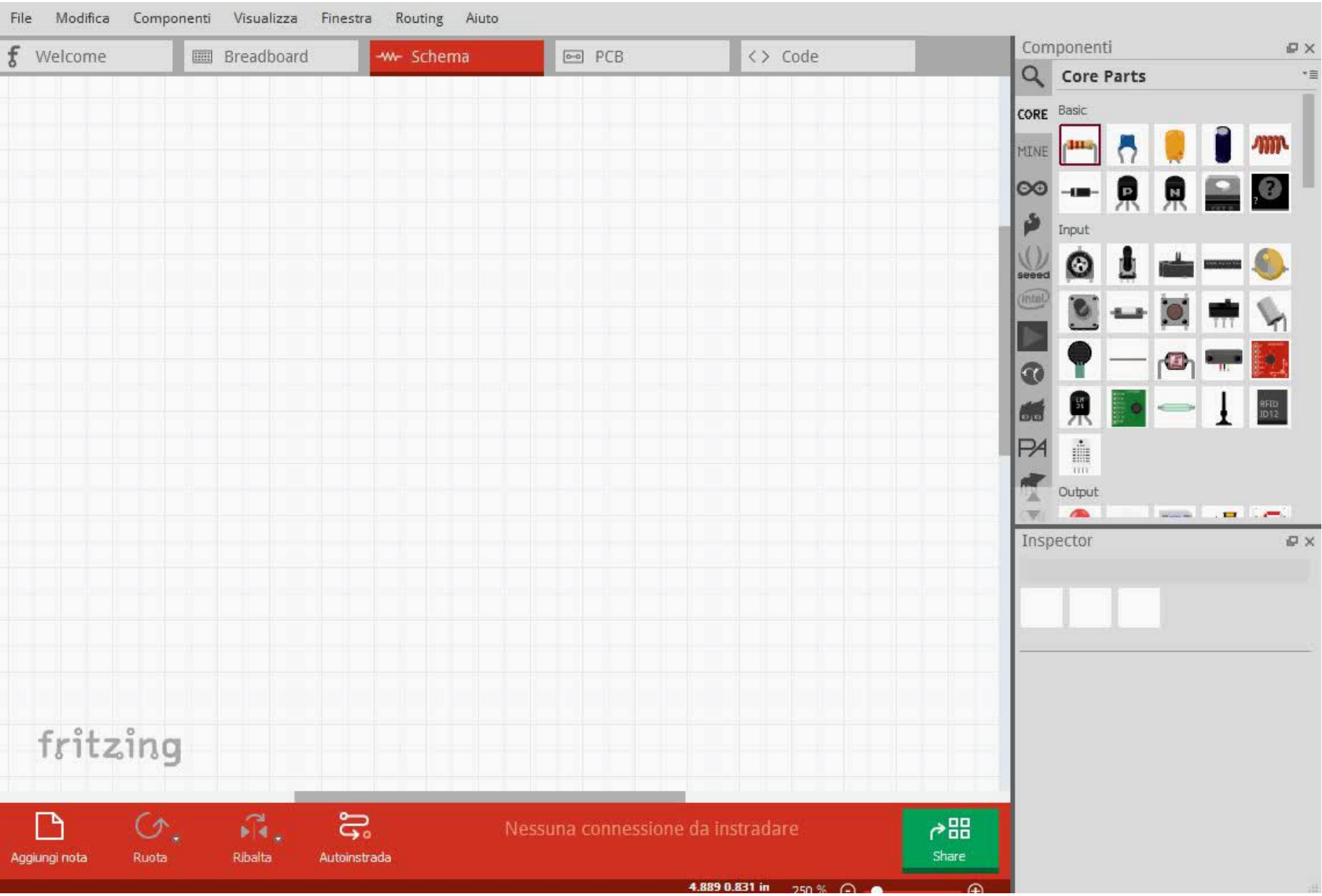


-12 V

+12 V

A ratsnest displays a set of connected connectors (a "net"), and it can suggest potential paths for routing between those connectors

GND


File
Modifica
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Finestra
Routing
Aiuto
Welcome
Breadboard
Schema
PCB
Code
Componenti
Core Parts
CORE
MINE
seeed
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Basic
Input
Output
Inspector
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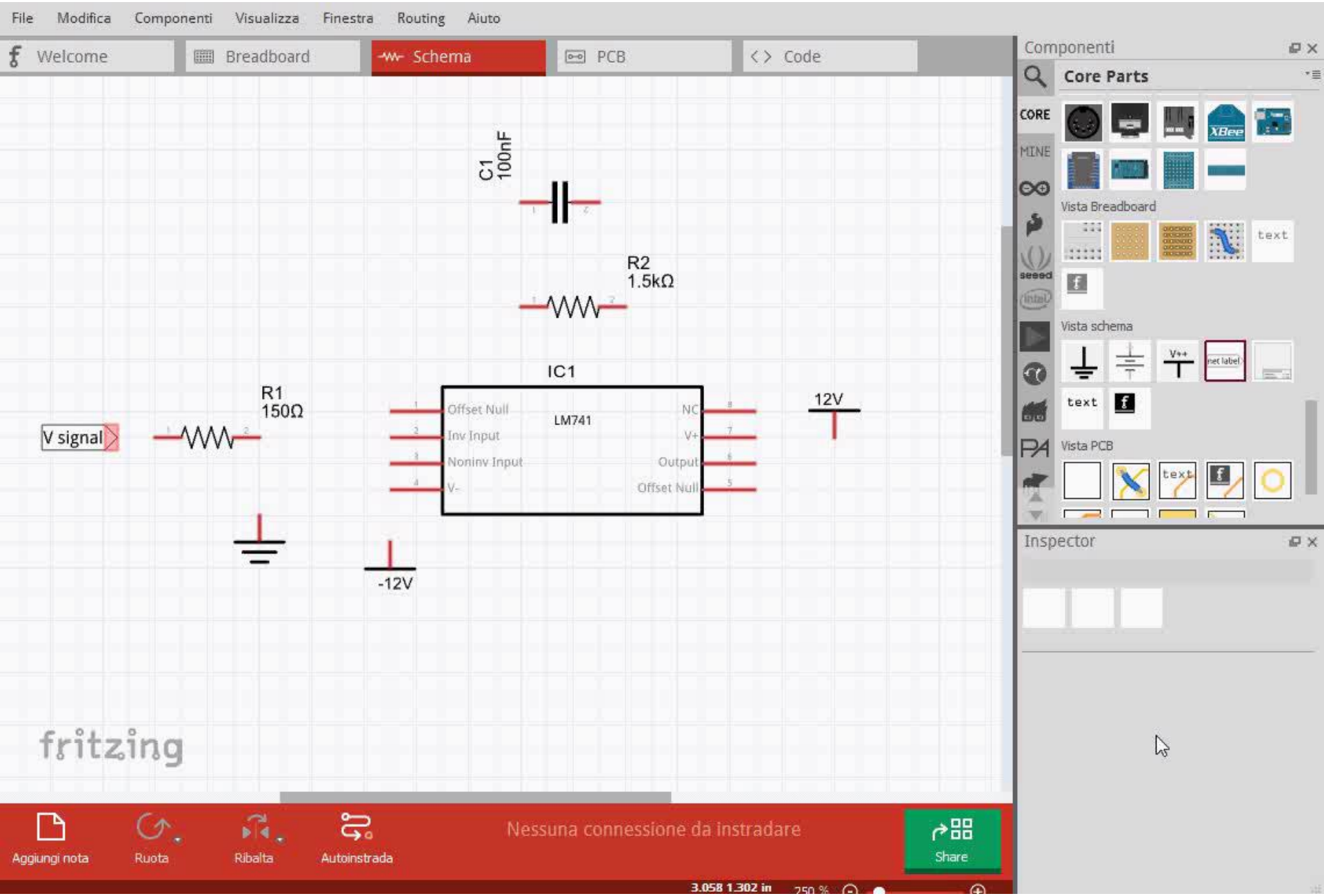
Ruota
Ribalta
Autoinstrada
Nessuna connessione da instradare
Share
4.889 0.831 in
250 %


File
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Routing
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Welcome
Breadboard
Schema
PCB
Code
C1
100nF
R2
1.5kΩ
IC1
R1
150Ω
V signal
Offset Null
Inv Input
Noninv Input
V-
LM741
NC
V+
Output
Offset Null
12V
-12V
fritzing
Componenti
Core Parts
CORE
MINE
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Vista schema
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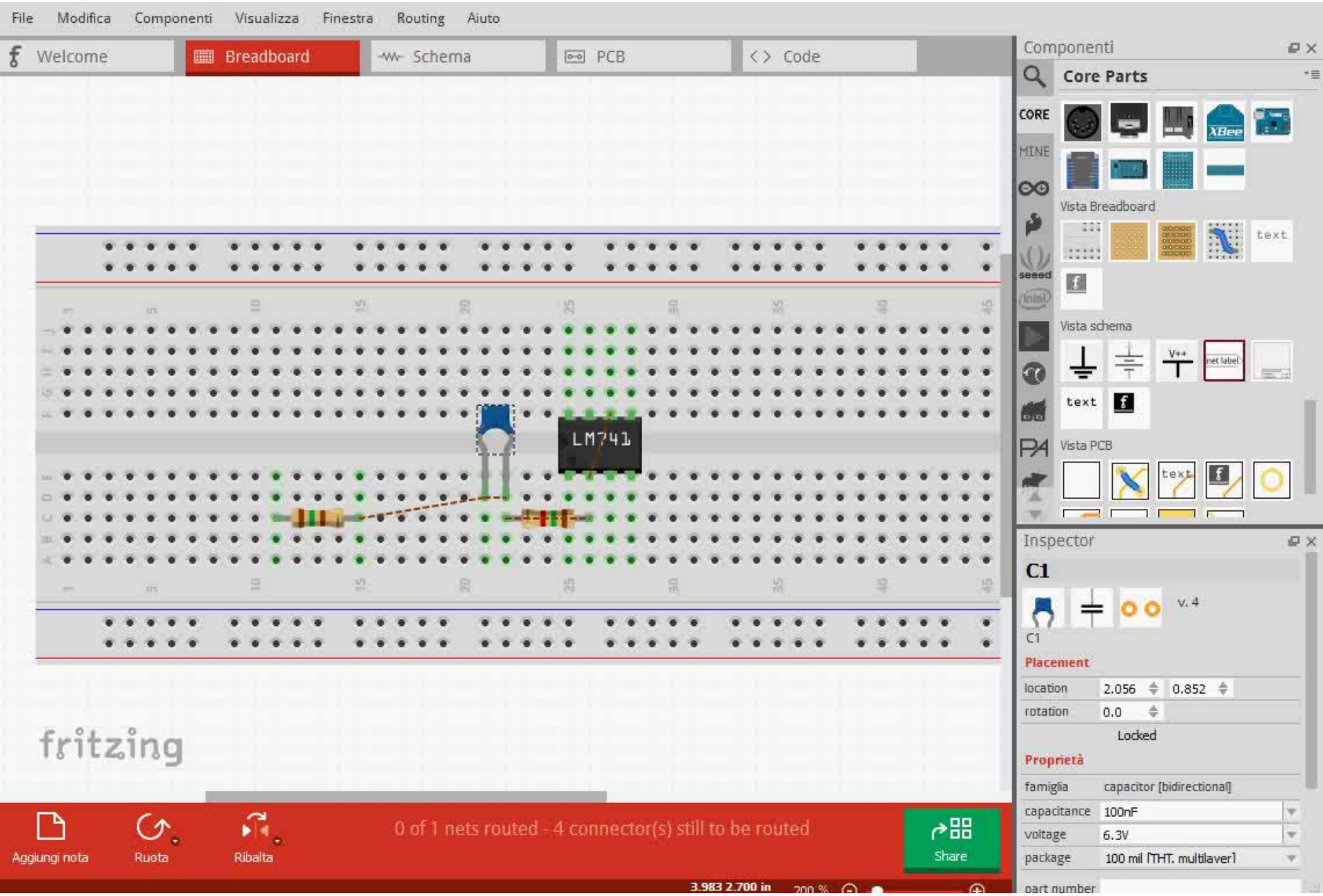
File
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Schema
PCB
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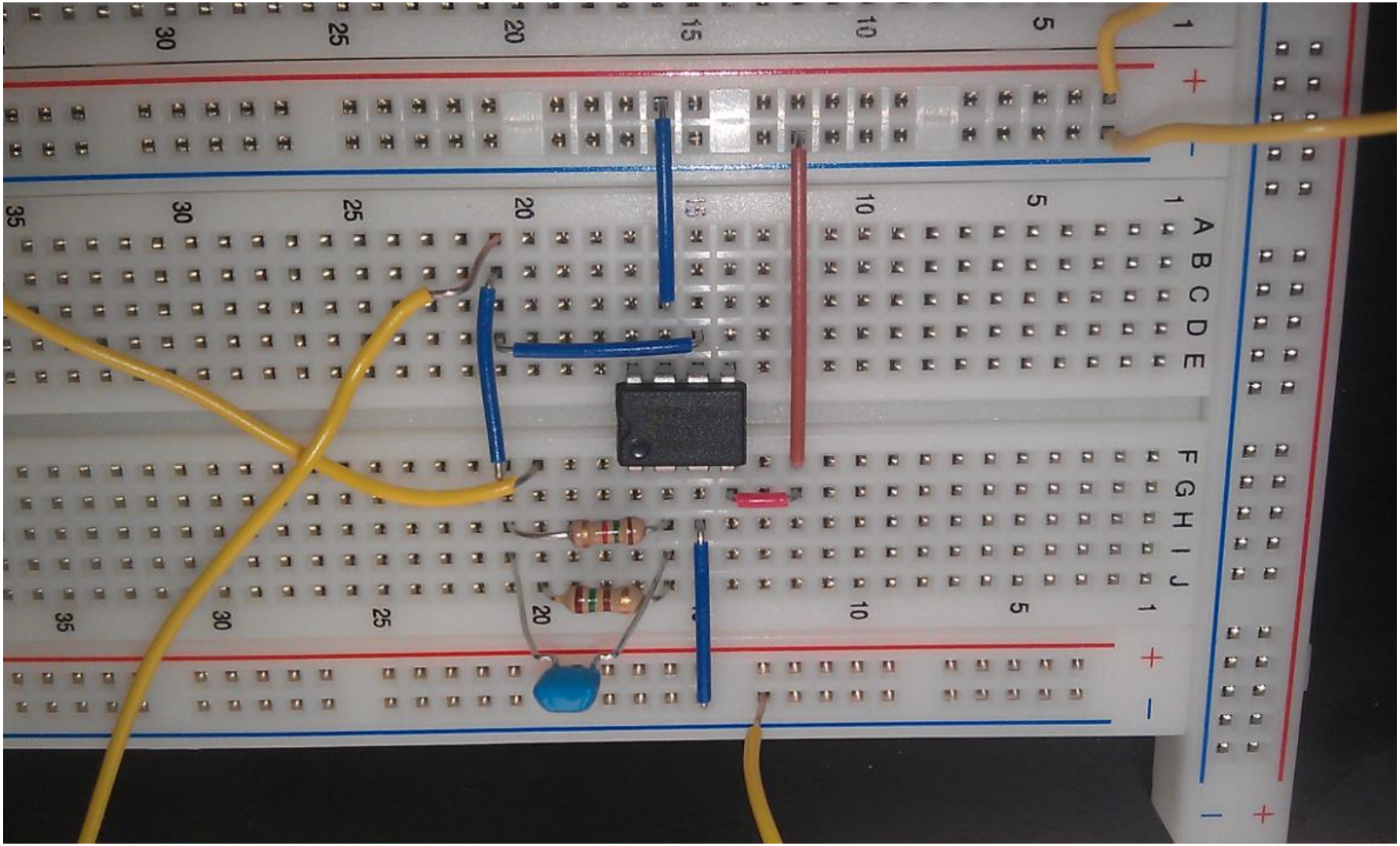
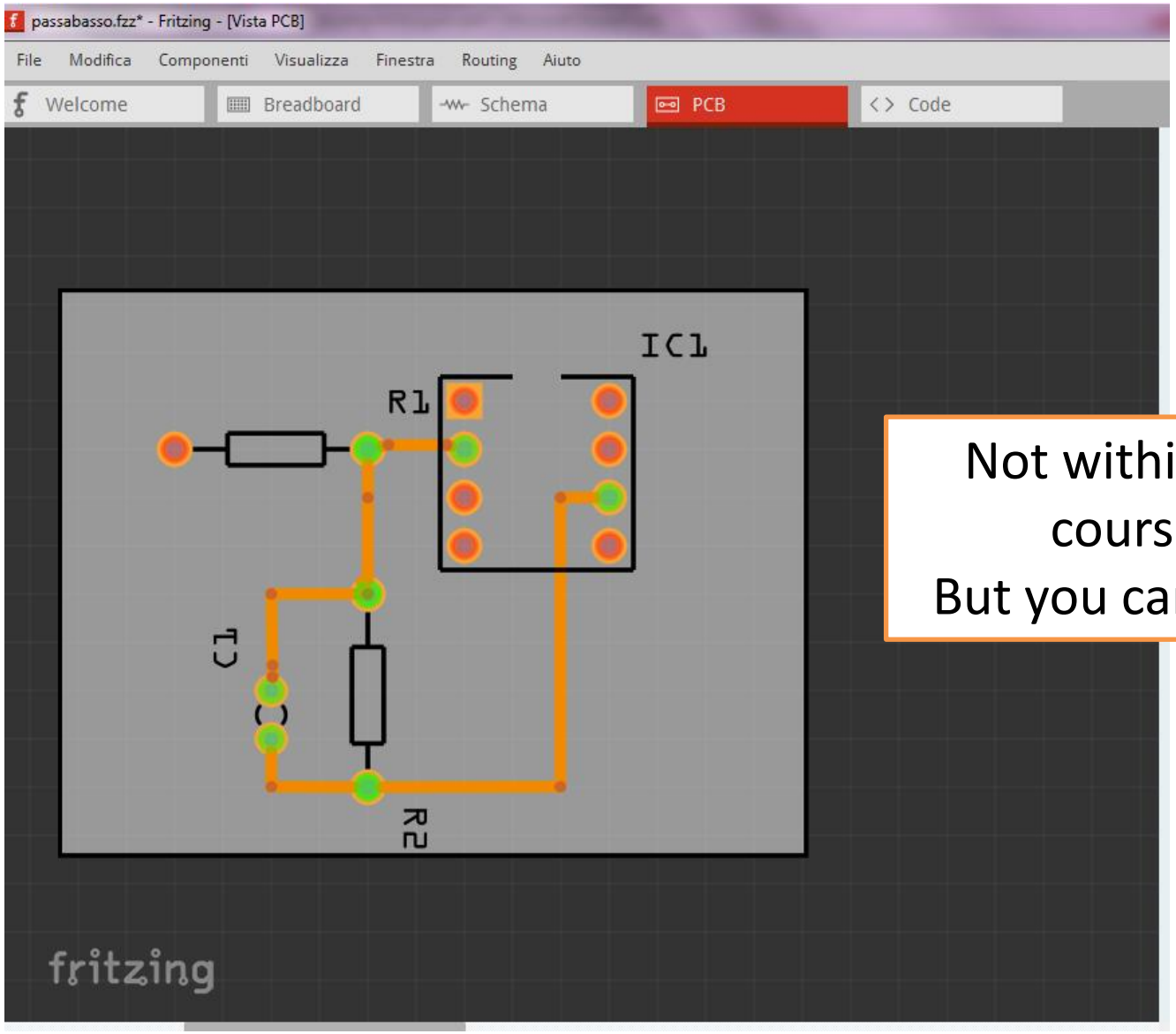
Vista Breadboard
Vista schema
Vista PCB
Inspector
C1
v. 4
Placement
location
2.056
0.852
rotation
0.0
Locked
Proprietà
famiglia
capacitor [bidirectional]
capacitance
100nF
voltage
6.3V
package
100 mil [THT, multilayer]
part number
Aggiungi nota
Ruota
Ribalta
0 of 1 nets routed - 4 connector(s) still to be routed
Share
3.983 2.700 in
200 %

And now…build the breadboard!

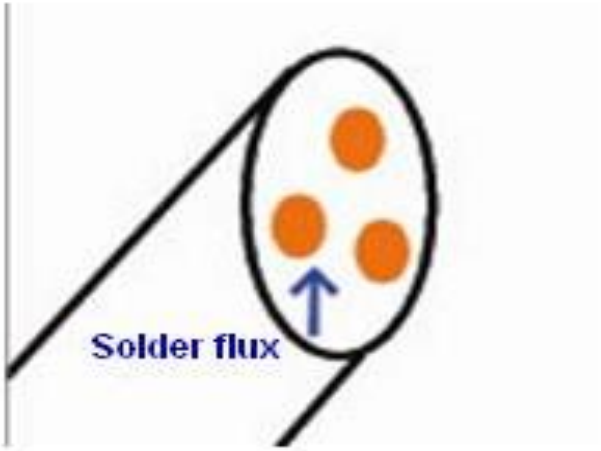


The PCB environment can be used to build PCBs…



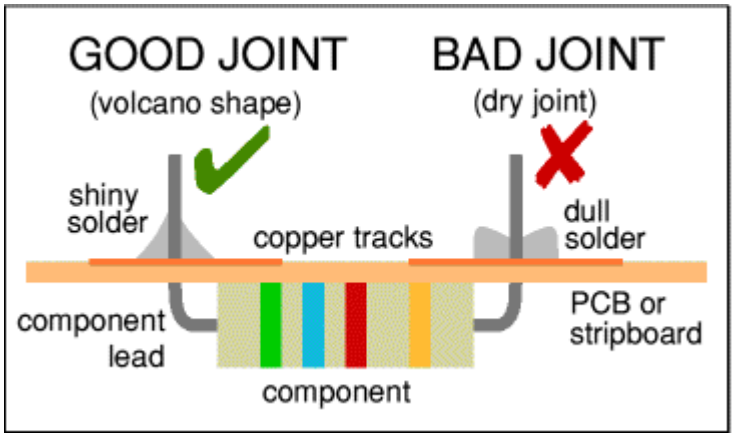
Not within this course,
But you can try!!!

Soldering…



Has “flux” inside. Flux is a wax-like material that has a few percent acid, for cleaning the oxide layer from wires being soldered

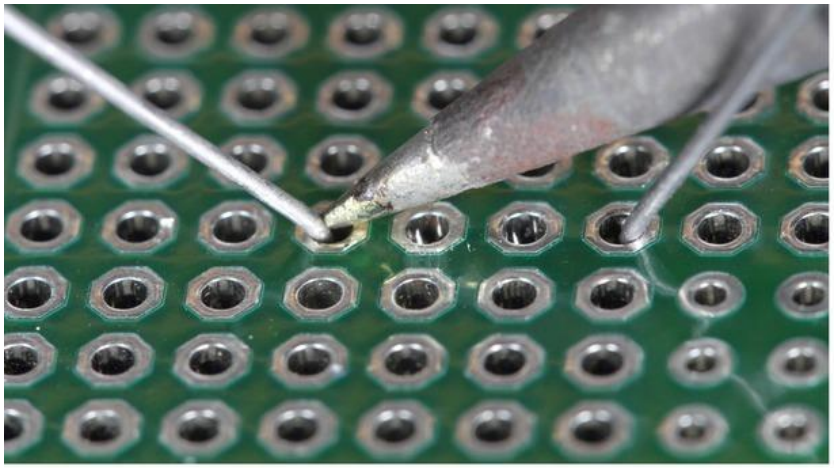
Soldering…


GOOD JOINT
(volcano shape)
BAD JOINT
(dry joint)
shiny solder
copper tracks
dull solder
component lead
PCB or stripboard
component

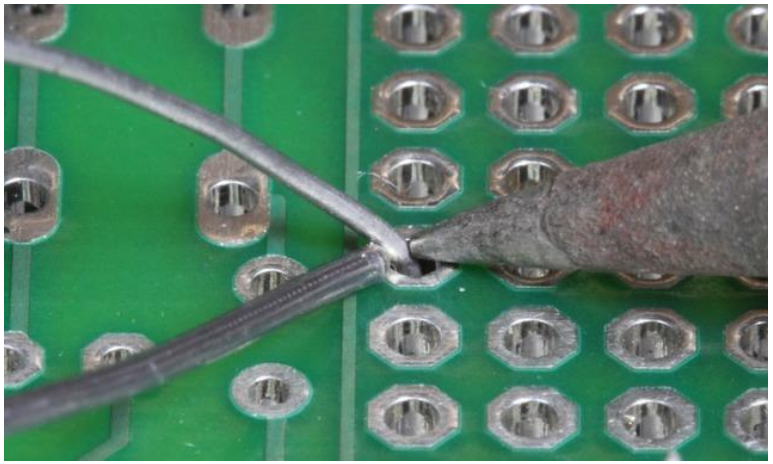

NET WEIGHT 16 OZ. (1 LB.)

Soldering…

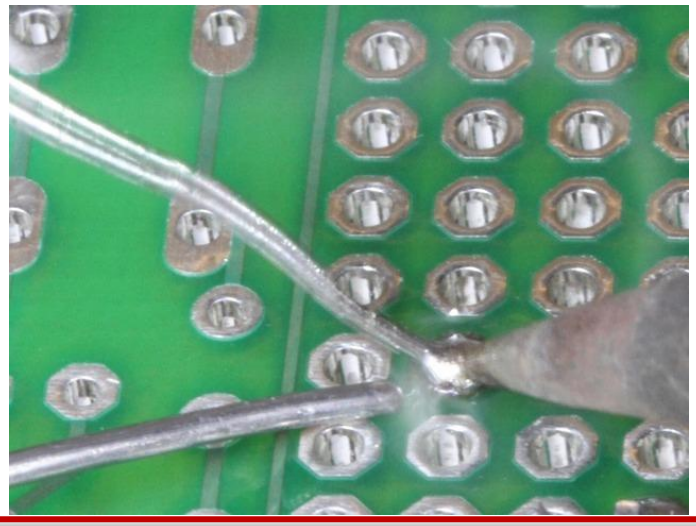
Heat the joint



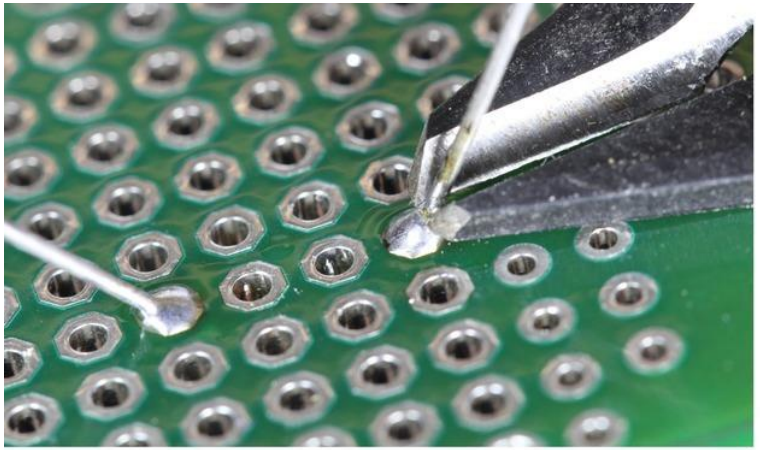
Apply the solder



Let It Flow



Let it cool, trim the Lead

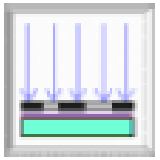


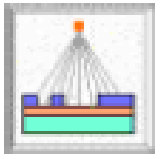
Soldering tips

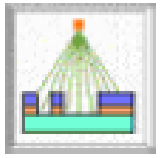
- Liquid solder conducts heat better than a dry tip, so it helps to put a dab of solder onto the tip before soldering. The associated flux can also help clean up the tip.
- It helps to “tin” the leads being soldered individually before actually trying to solder them together.
- The smoke that comes mostly from burning flux→ not healthy to breathe it in.
- Don’t hold solder in mouth

Soldering irons → Temperature regulated ones are crucial, Tips are special – if you decide that you want a sharper tip, you can sand the tip down to a point, but it will dissolve a little bit each time you use it!

Steps for PCB fabrication



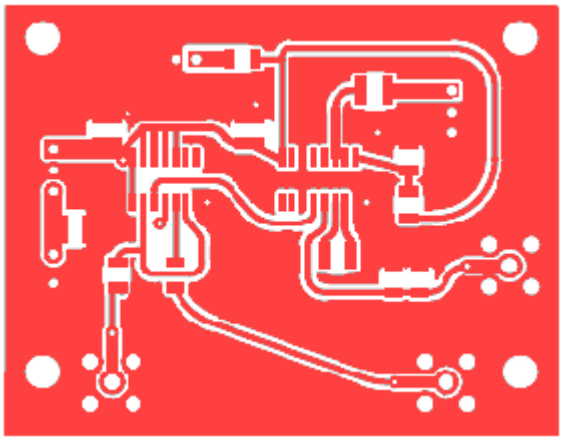




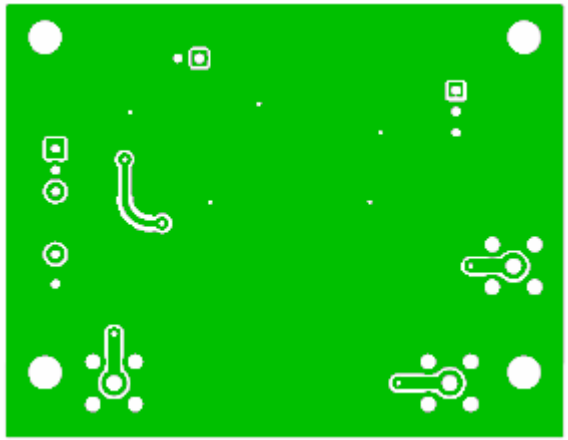
1. **Layout design** (CAD)
2. **Artwork generation or mask** (Laser printer)
3. **Board inspection and cleaning**
4. **Board Exposure/imaging** (UV-light)
5. **Development** (Soften UV-insolated areas)
6. **Etching** (Removal of UV-insolated areas)
7. **Drilling** (Build holes and vias)
   Solder mask (Protection of copper tracks)
   Silkscreen (Component lettering)
8. **Final inspection and test**

Printed Circuit Boards (PCBs)

1. **Generate a layout**, by using a PCB software. There are programs that are free, and very expensive ones:
   - Eagle, from http://www.cadsoftusa.com/
   - Kicad, from http://www.kicad-pcb.org/display/KICAD/KiCad+EDA+Software+Suite
   - Fritzing, from http://fritzing.org/home/
   - ORCAD, from http://www.orcad.com/



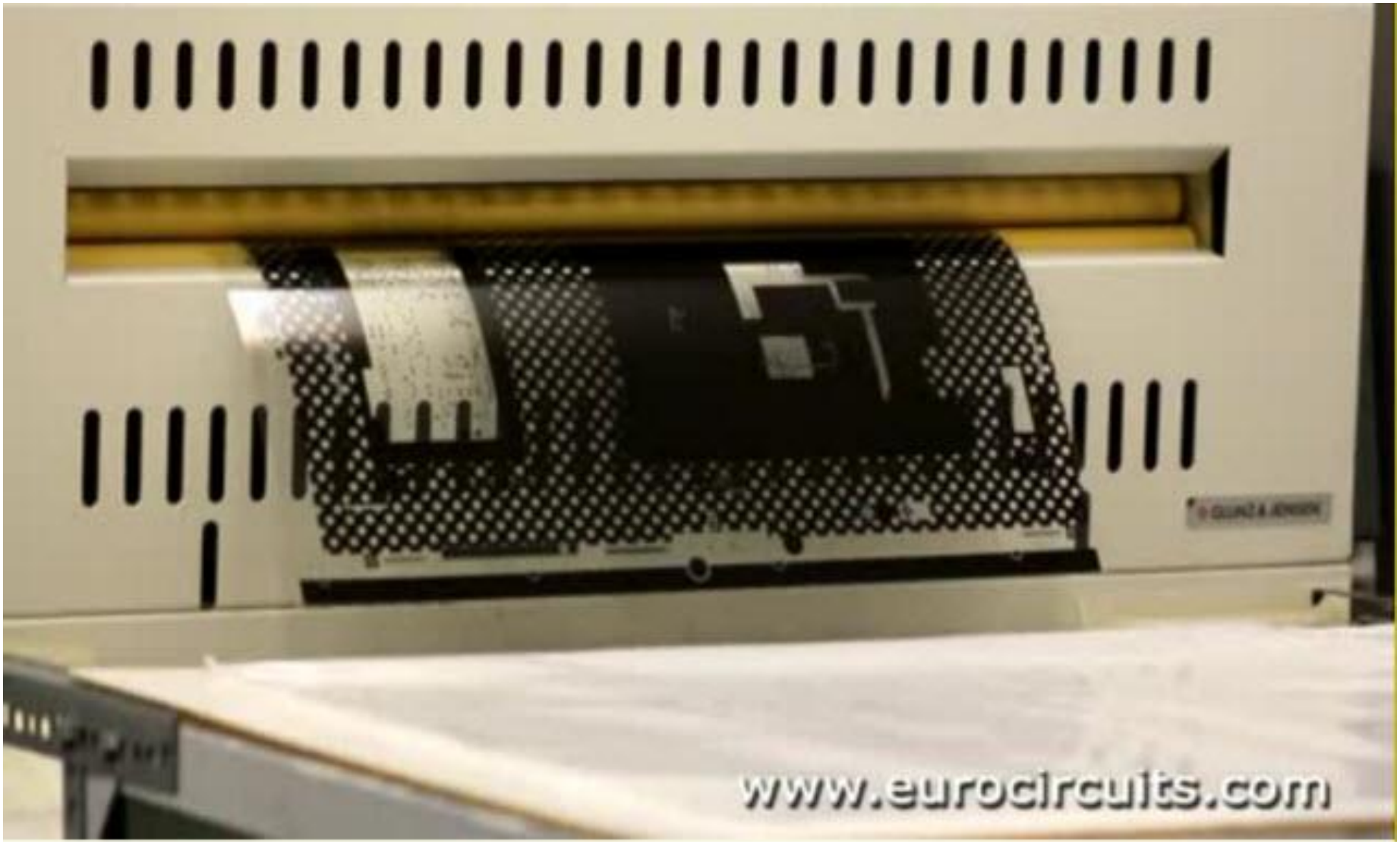
Top



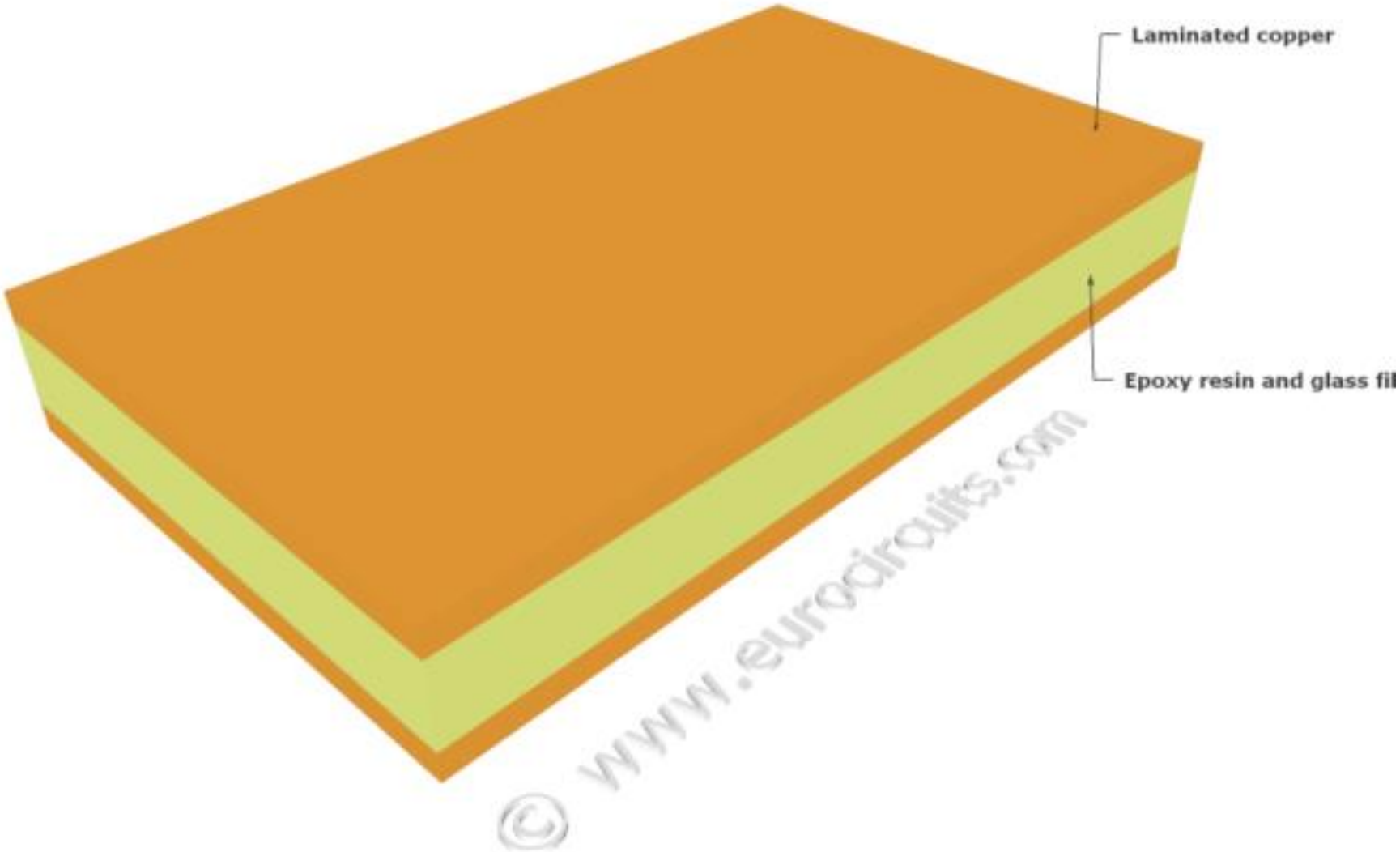
Bottom

For our process, we generate a “positive” image: colored parts (which print as black) will be copper, white parts no copper.

Generate the mask



Starting point: a copper layer



The copper panel is coated with a photoresist

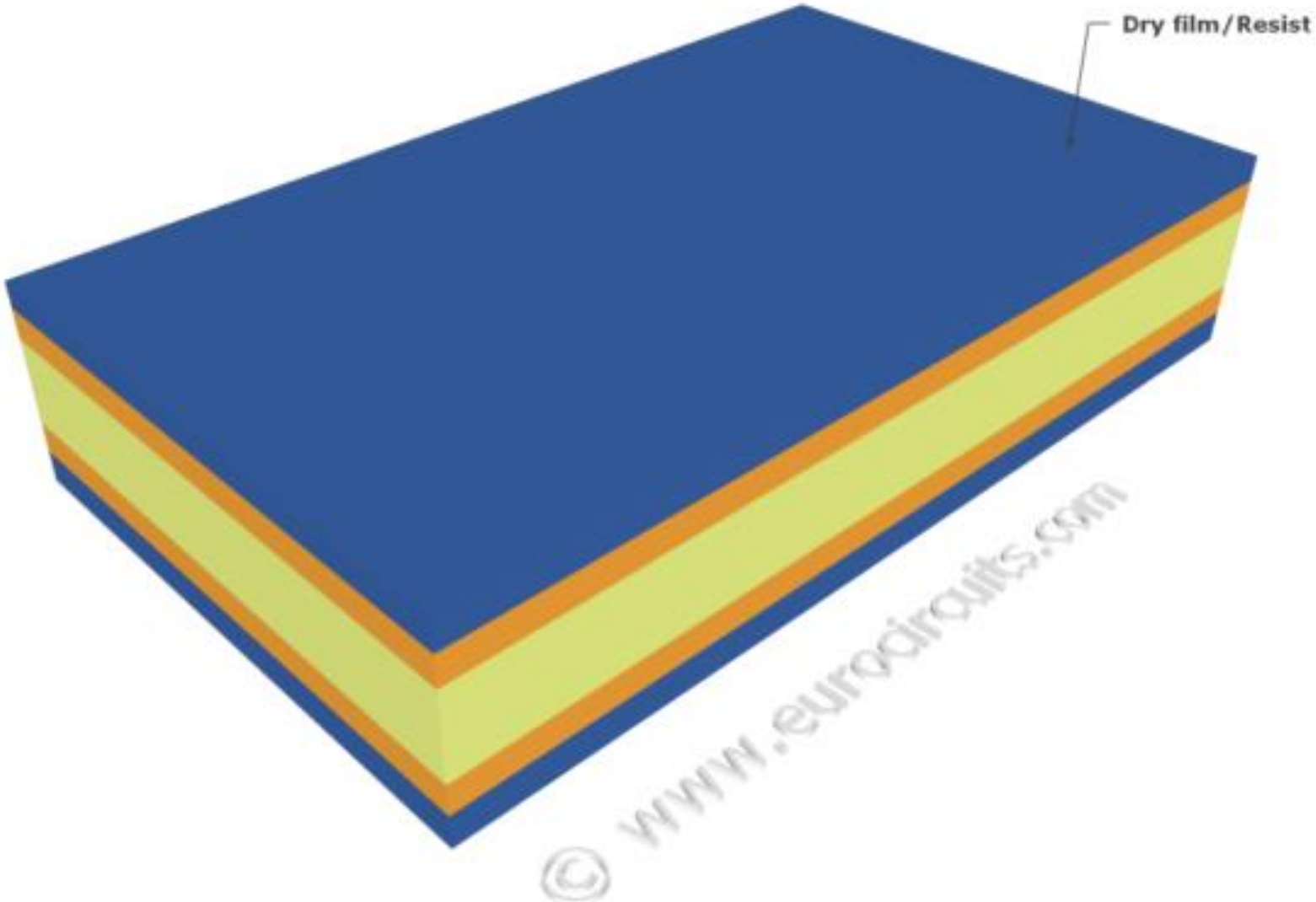
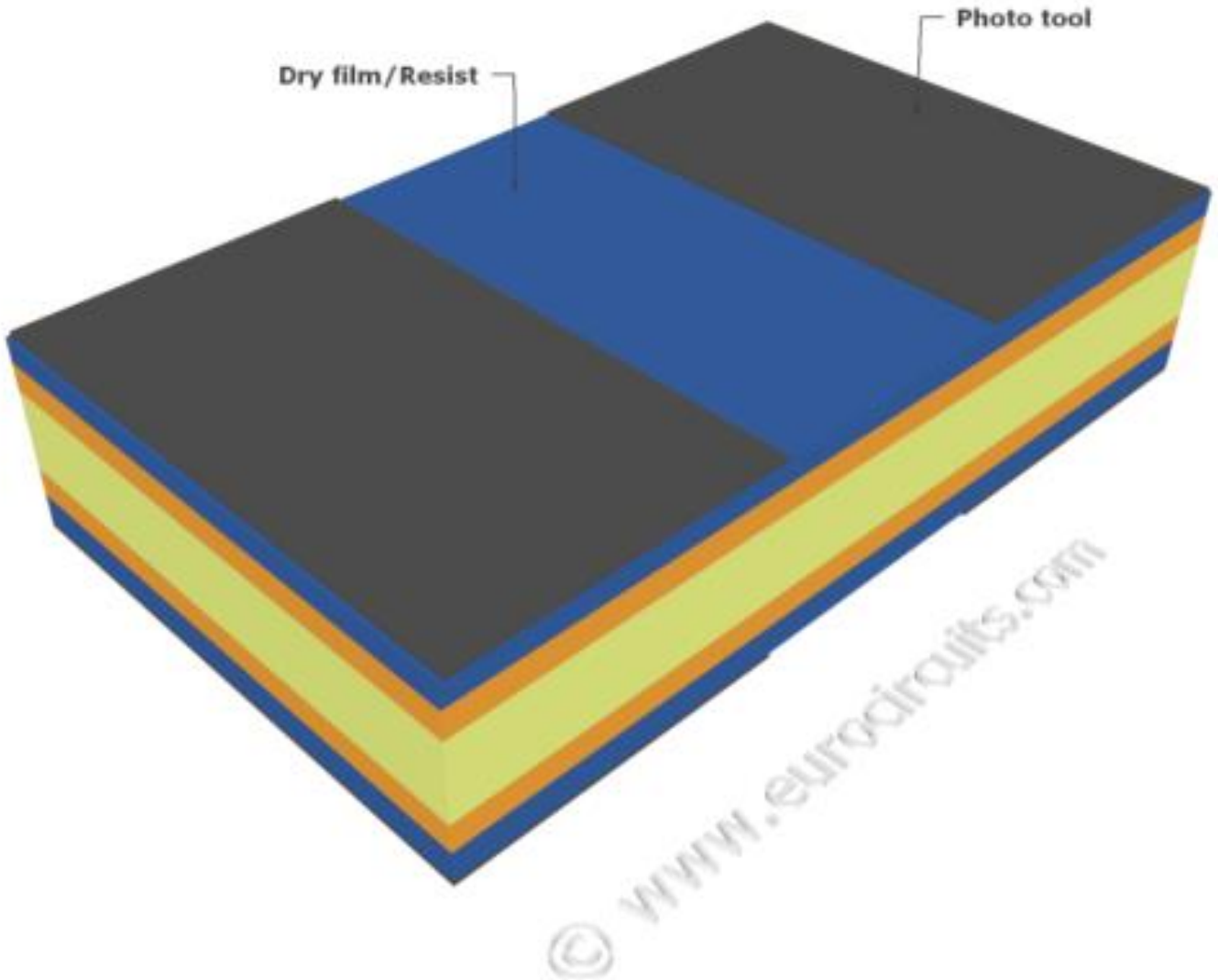
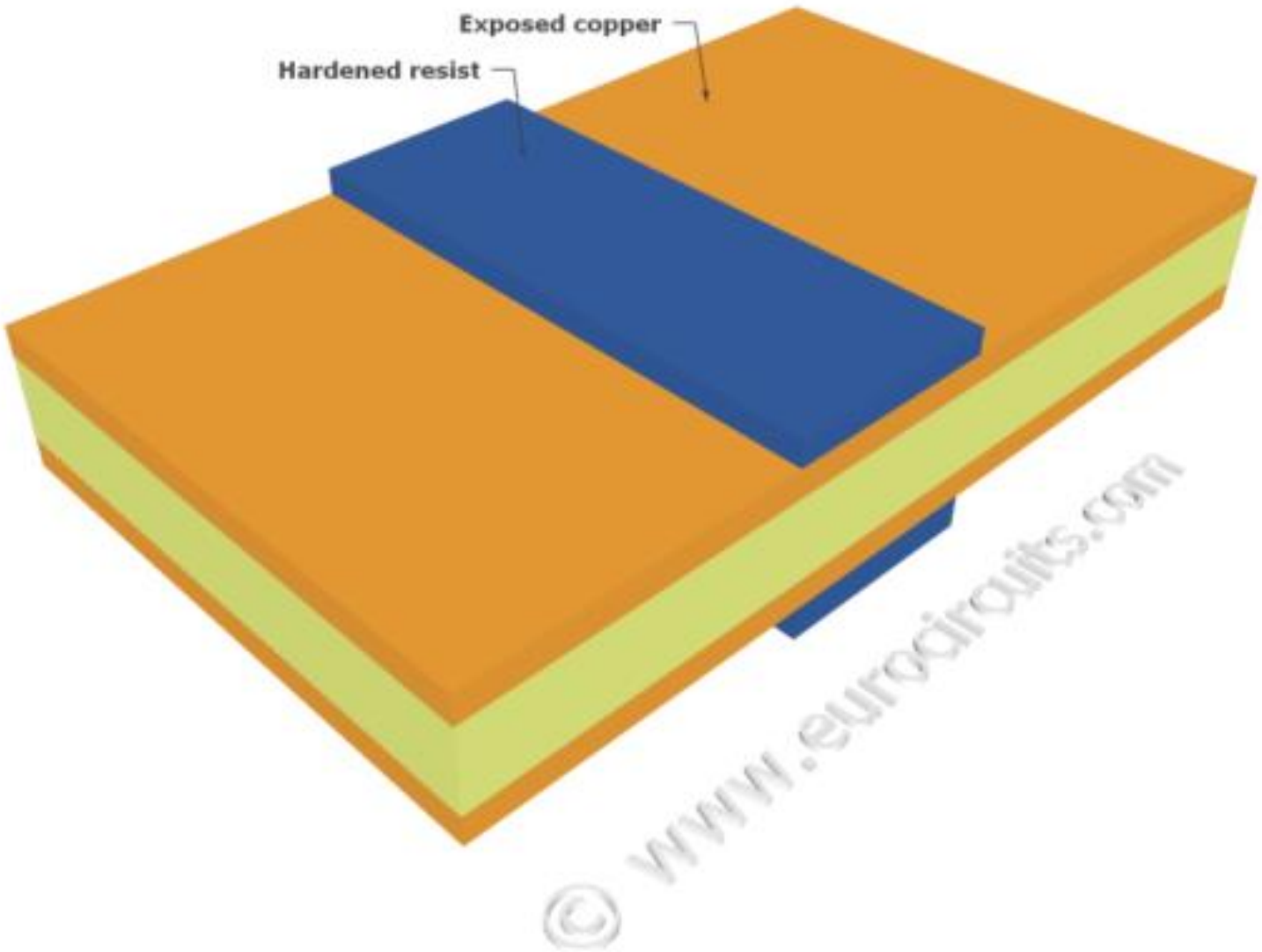


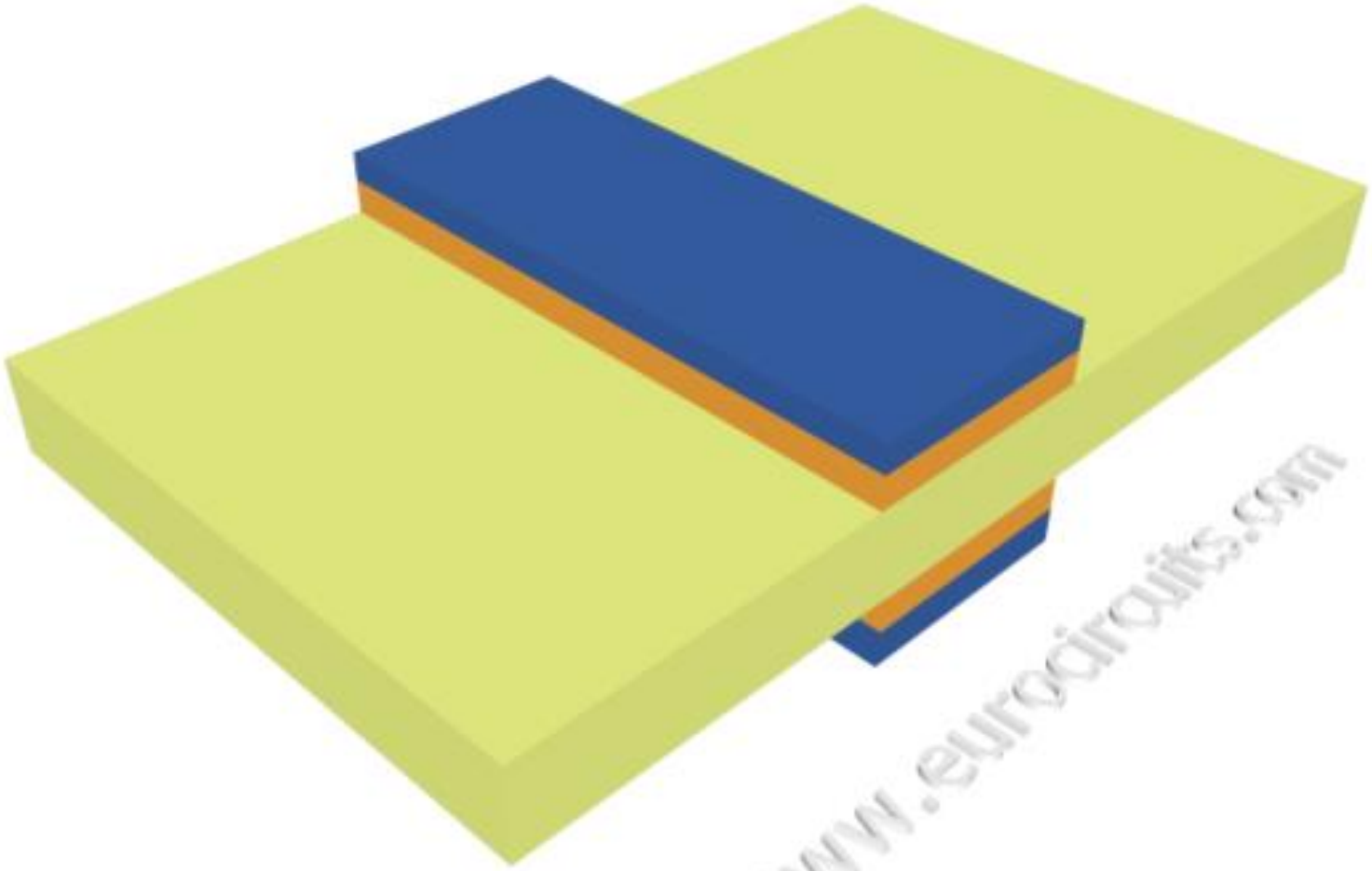
Photo tool is superimposed to resist; UV light to harden resist



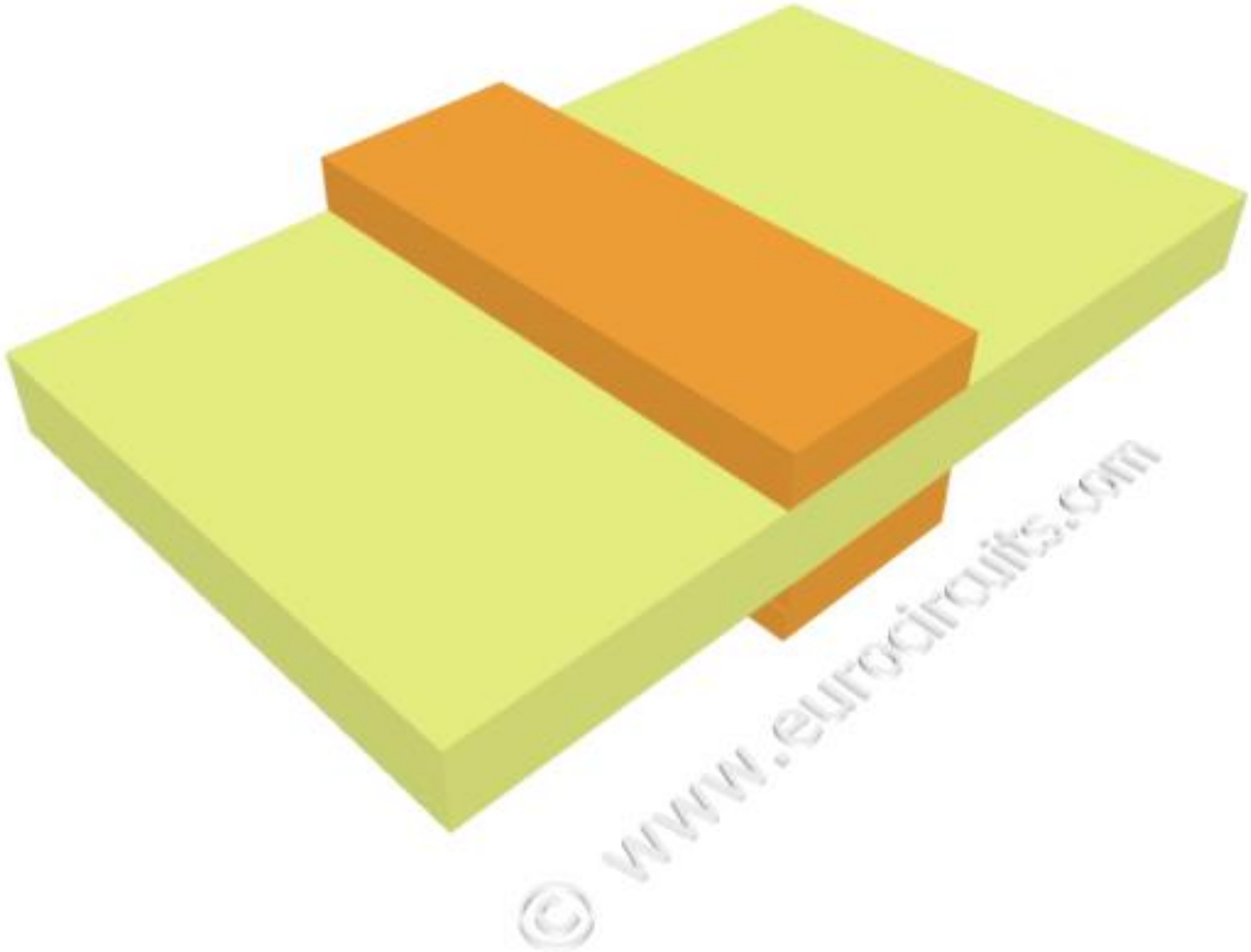
Powerful alkali solution to remove unhardened resist



Removal of the unwanted copper using an alkaline solution



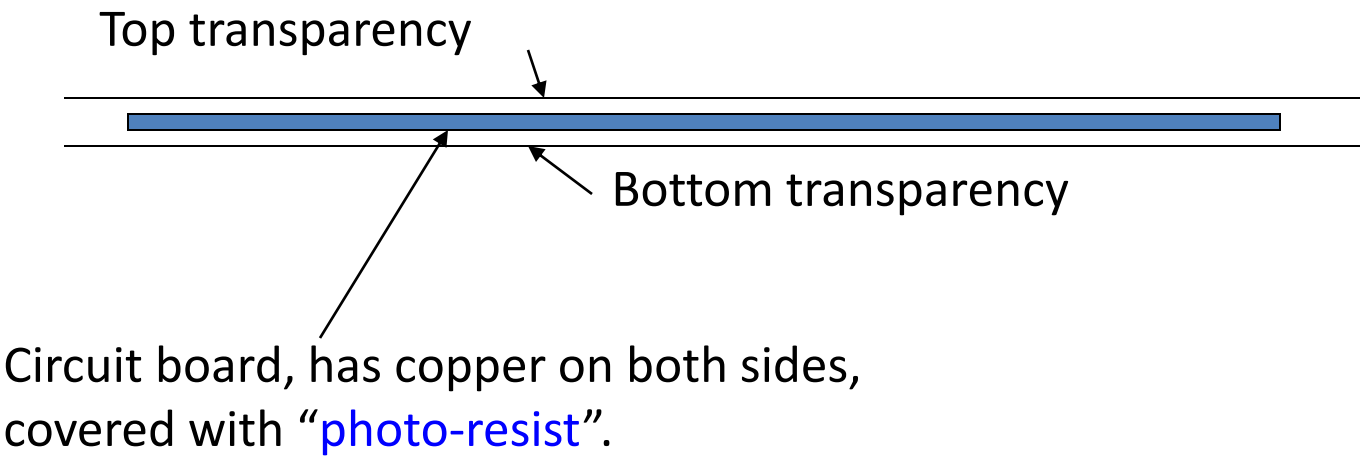
Removal of the (blue) photoresist



Methods for PCB fabrication: with ferric chloride

Subtractive process

1. Use laser printer to print layout (also called artwork) on a transparency
2. Align top and bottom, and tape them together.
3. Slip a pre-sensitized board between them.

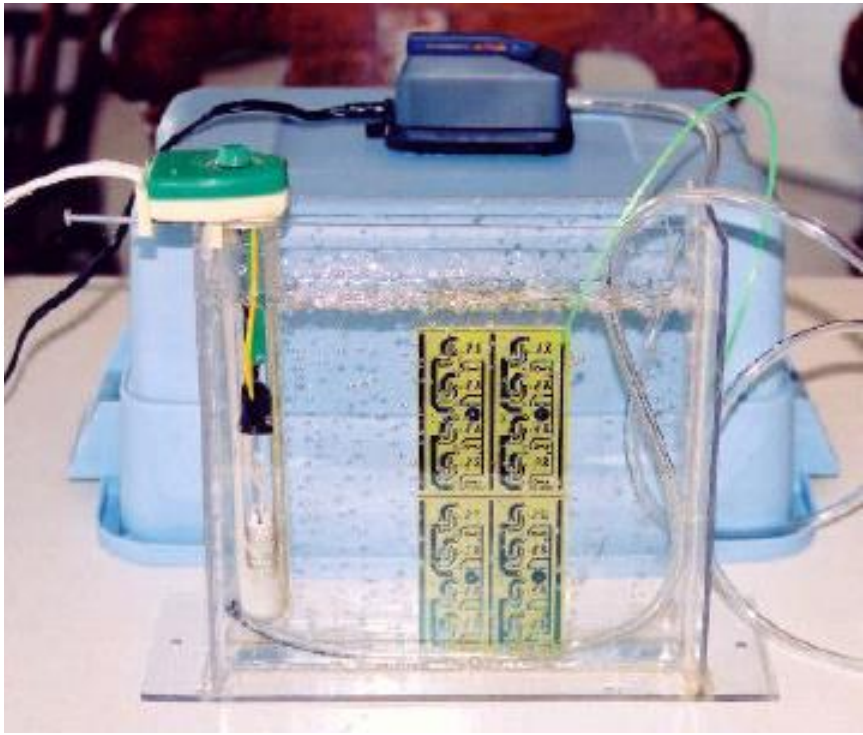


Methods for PCB fabrication (1): with ferric chloride

4. **Expose in UV box for 5 minutes**. The UV goes through the clear parts of the transparency, and interacts with the photoresist.

Methods for PCB fabrication (1): with ferric chloride

4. **Soak board in developer** – this washes off the exposed photoresist.
5. **Rinse developer off using water**
6. **Etch in Ferric Chloride solution.** The photoresist that is still on the copper prevents the copper from being etched, at least for a while. Etching usually completes in 15-45 minutes, depending on how old the solution is

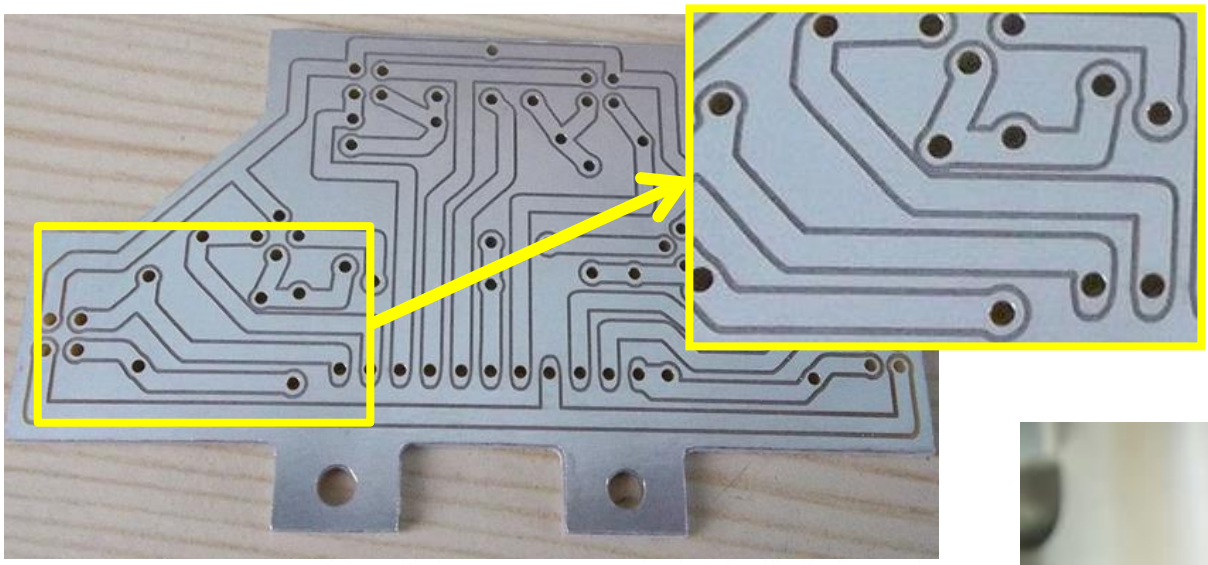


Problems with ferric chloride!

- The ferric chloride solution is highly irritating!
- It will also eat holes in your clothes, if it gets on them and dries there. ($\rightarrow$ mysterious little holes next time you wear them)
- Disposal/environmental problem!

Iron chloride is toxic, highly corrosive and acidic. The anhydrous material is a powerful dehydrating agent. Although reports of poisoning in humans are rare, ingestion of ferric chloride can result in serious morbidity and mortality

PCB Milling

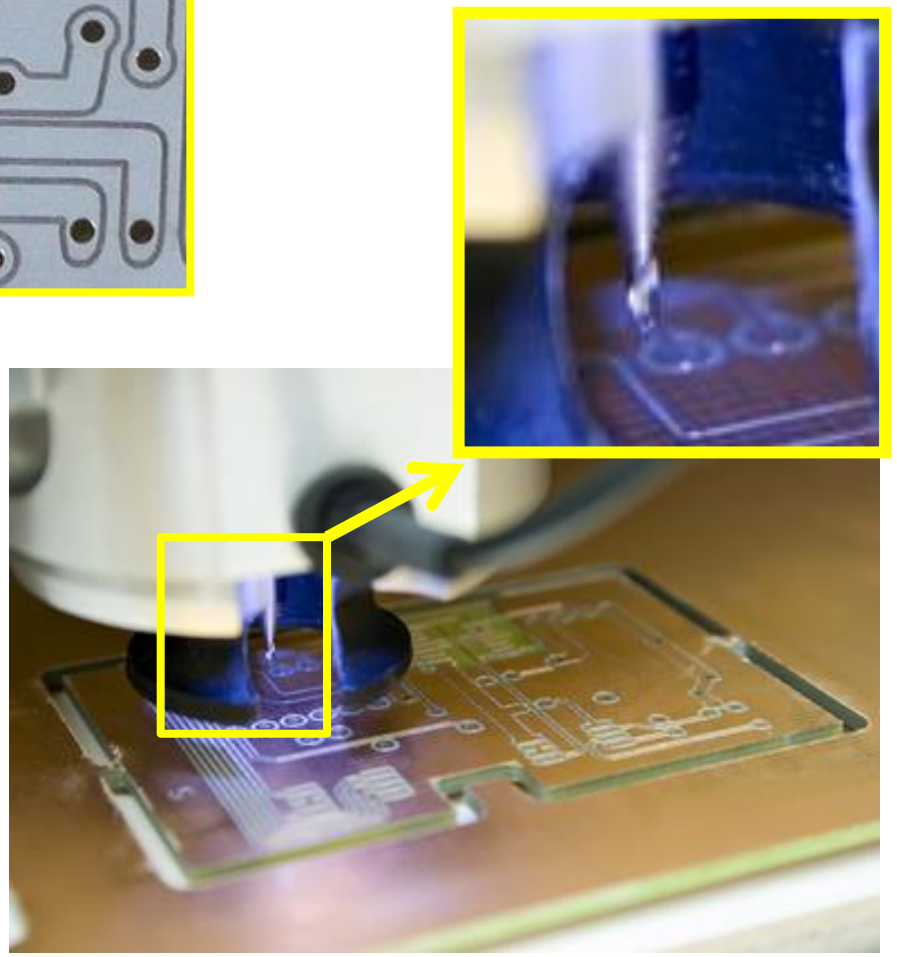


Another subtractive process

PCB Milling (isolation milling) → Removes areas of copper from a sheet (constituted by FR4 substrate with a thin copper layer)

This is a non-chemical process → safer, office- or lab-level production

In production → CNC milling can not replace etching (it is used for drilling vias!)

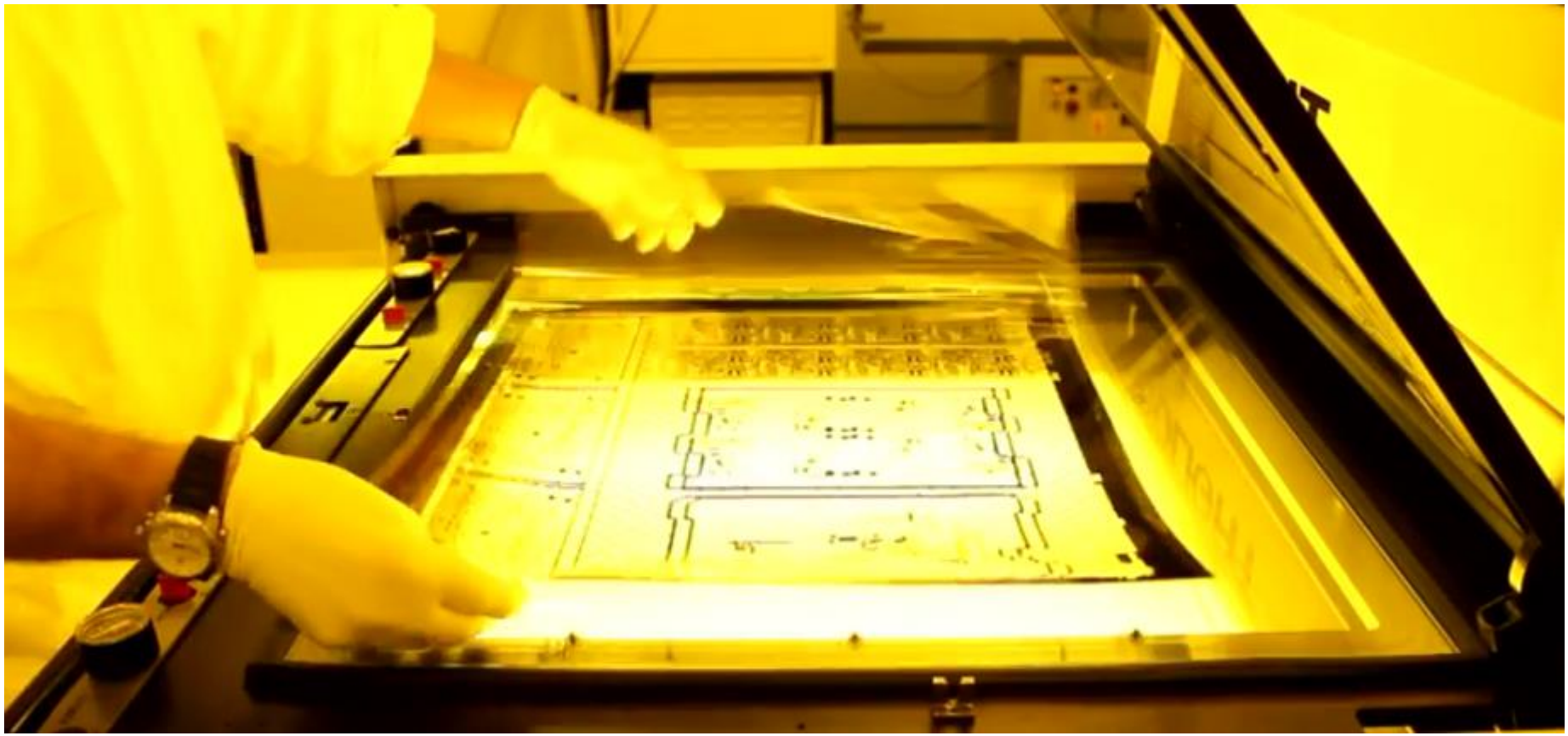


CNC=computer numerical control

How to fabricate PCBs?

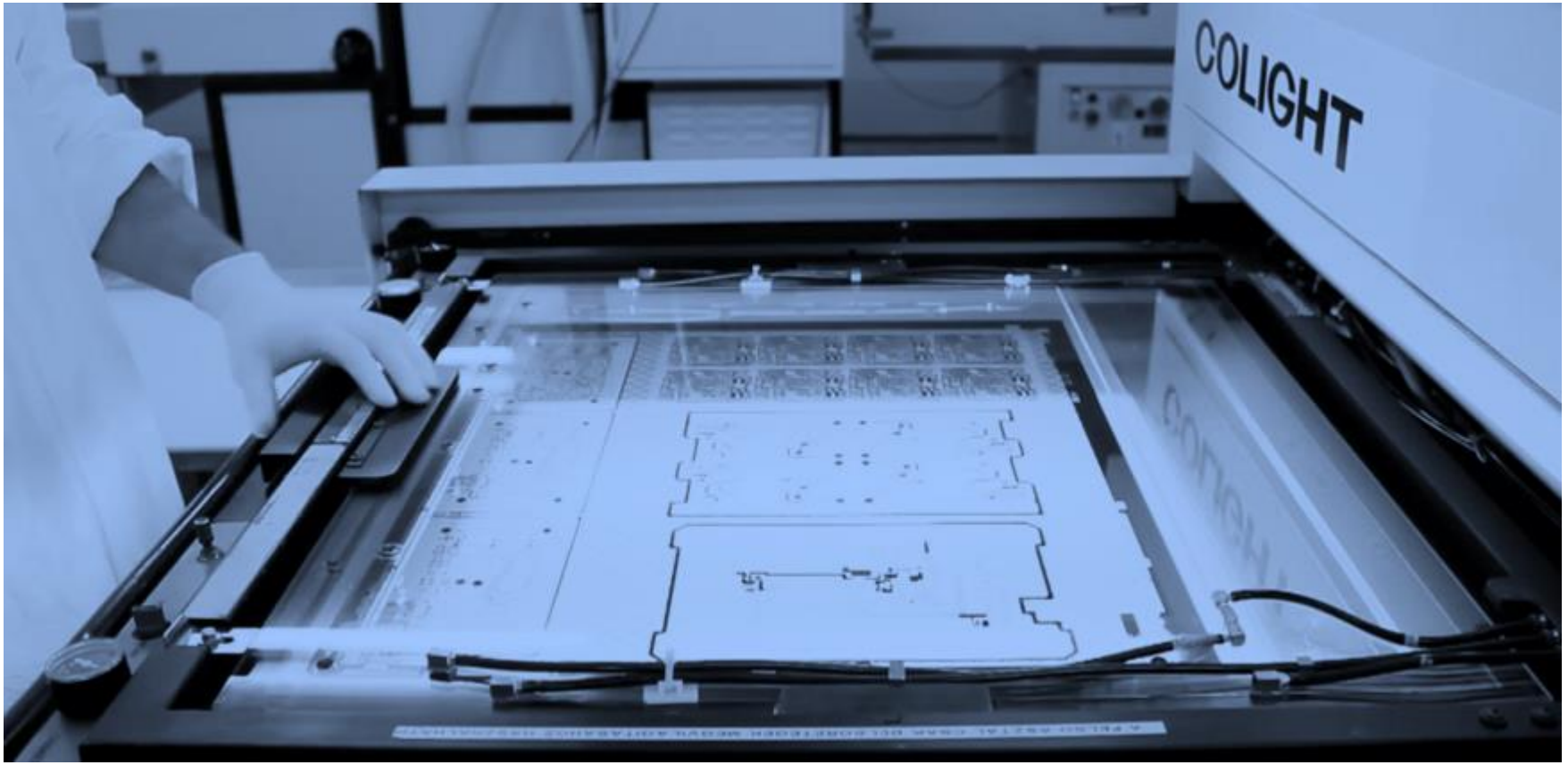
Additive method → copper is plated on a substrate with the desired pattern

- The surface of the substrate is degreased, and a layer of photoresist material is pressed onto the surface (photoresist is a polymer that becomes more soluble when exposed to UV light)
- The circuit pattern mask is laid on top of the photoresist



How to fabricate PCBs?

- The panels are exposed to UV light
- The mask is clear in the areas of the circuit pattern → The photoresist in those areas becomes soluble

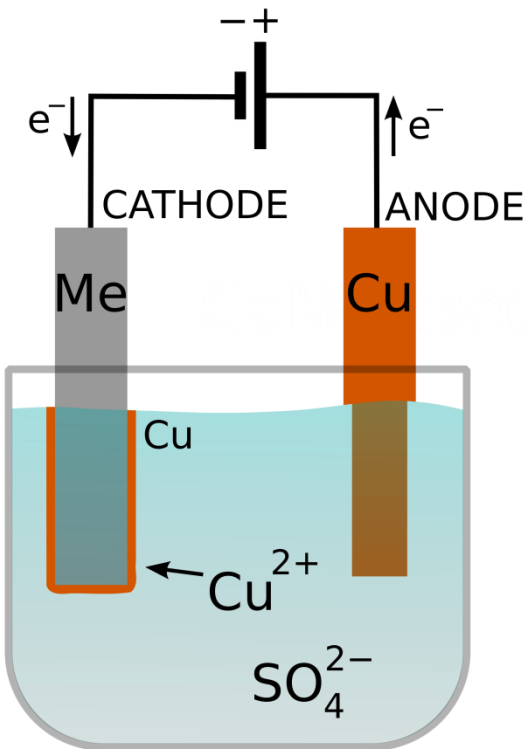


How to fabricate PCBs?

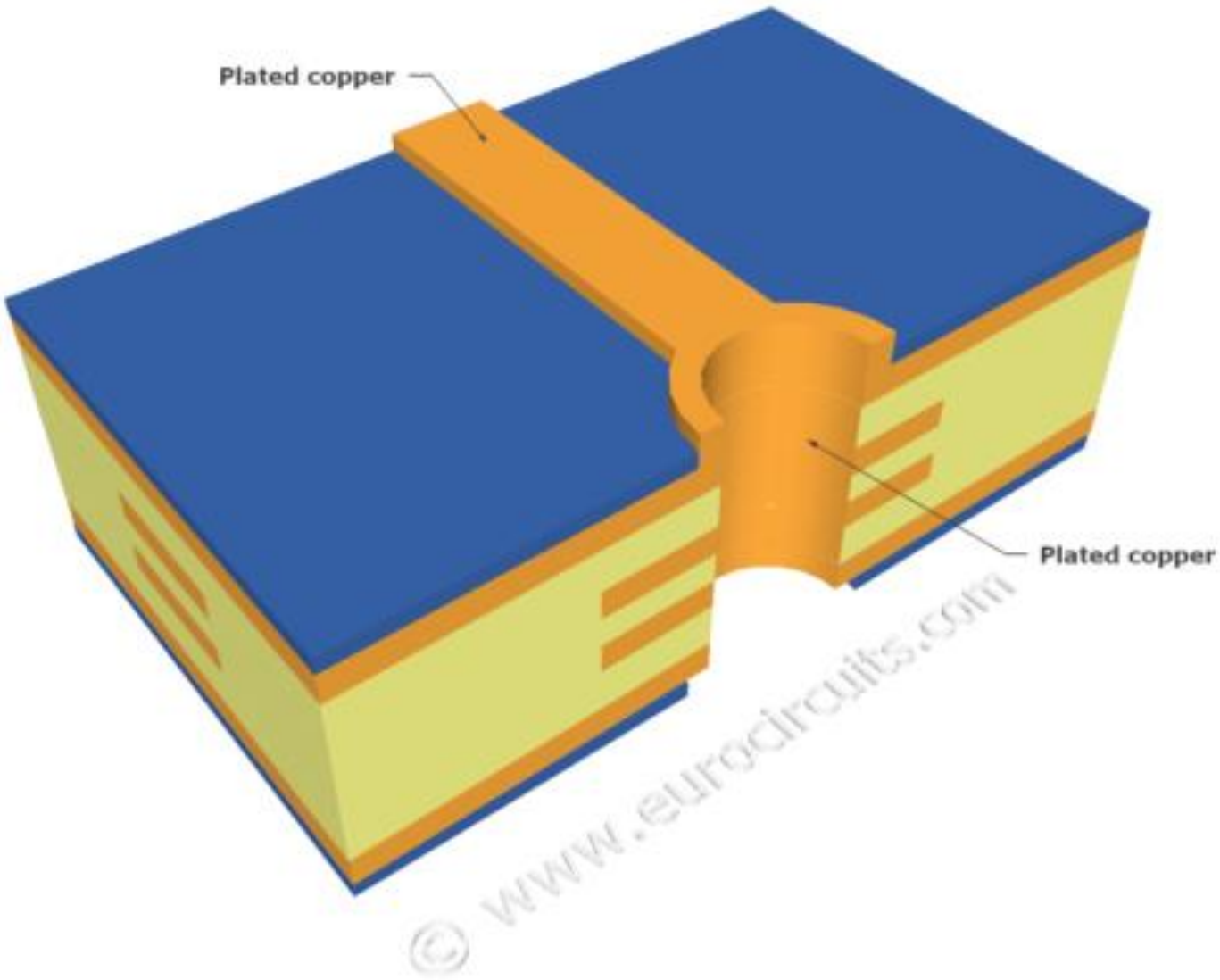
- The mask is removed, and the surface is sprayed with an alkaline developer that dissolves the irradiated photoresist

How to fabricate PCBs?

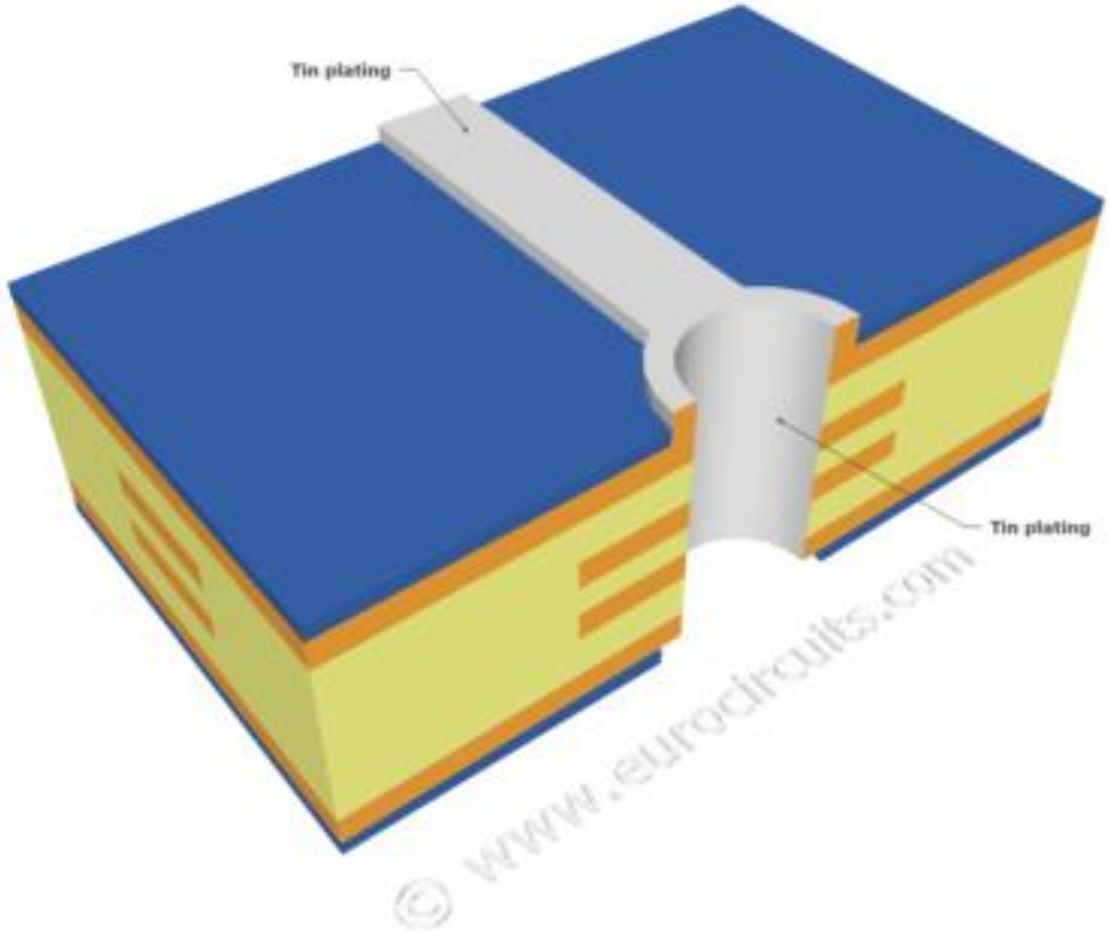
- The panels are then electroplated with copper (thickness 25-50 µm) → the areas covered by photoresist can not act as a cathode, and are not plated; tin lead is used as a protective coating to prevent copper from oxidizing



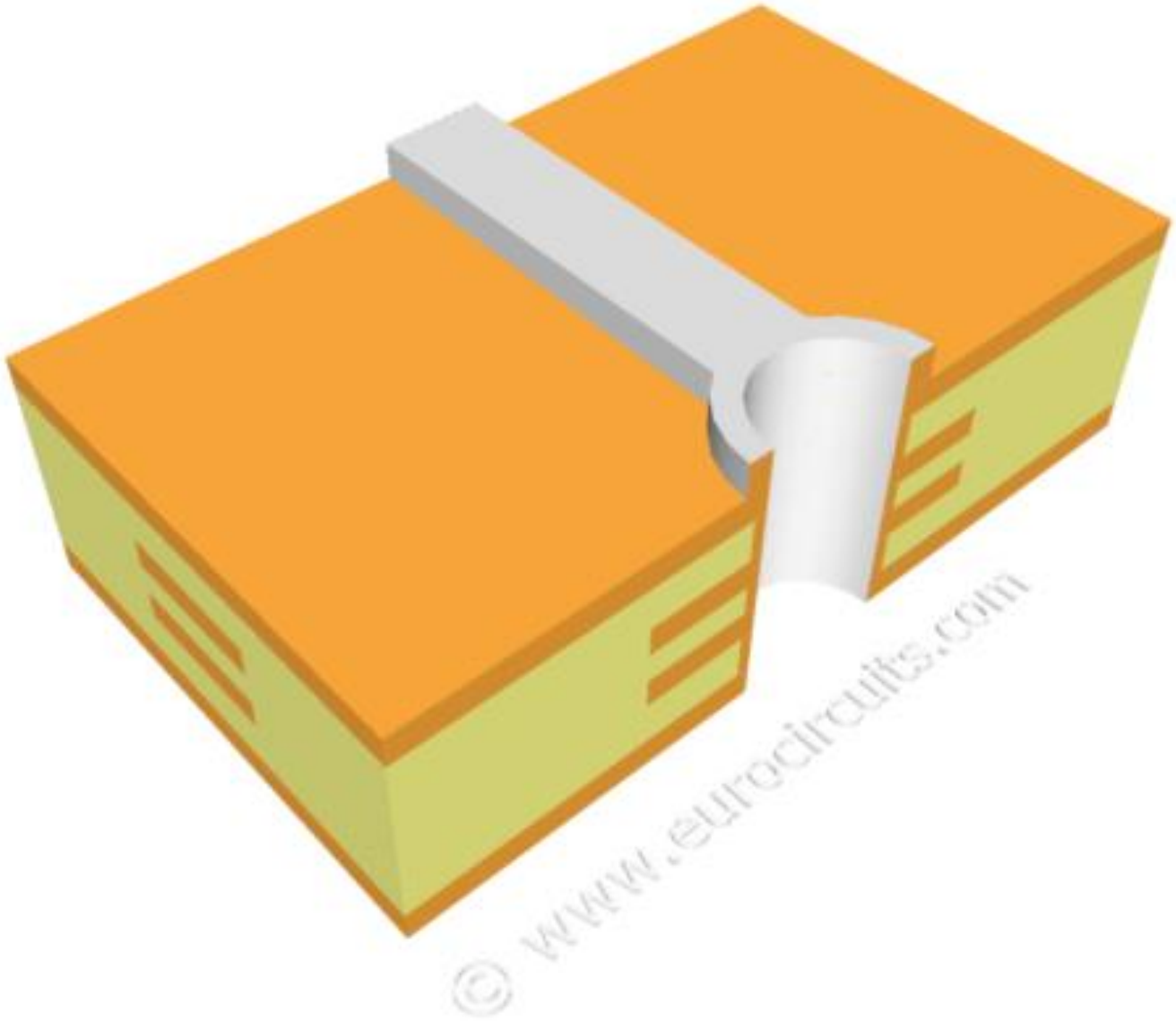
Adding the plated copper



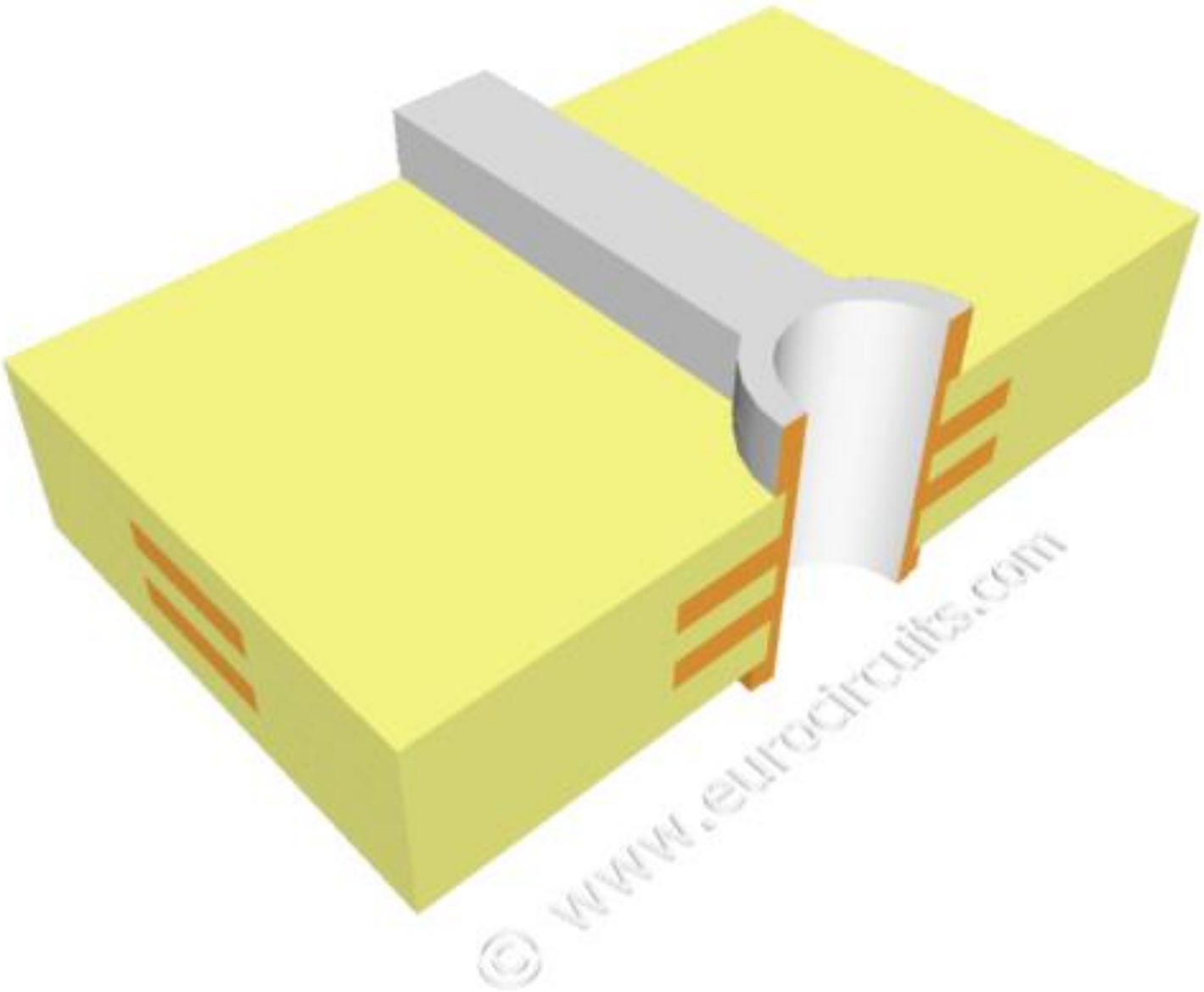
Adding a thin layer of tin



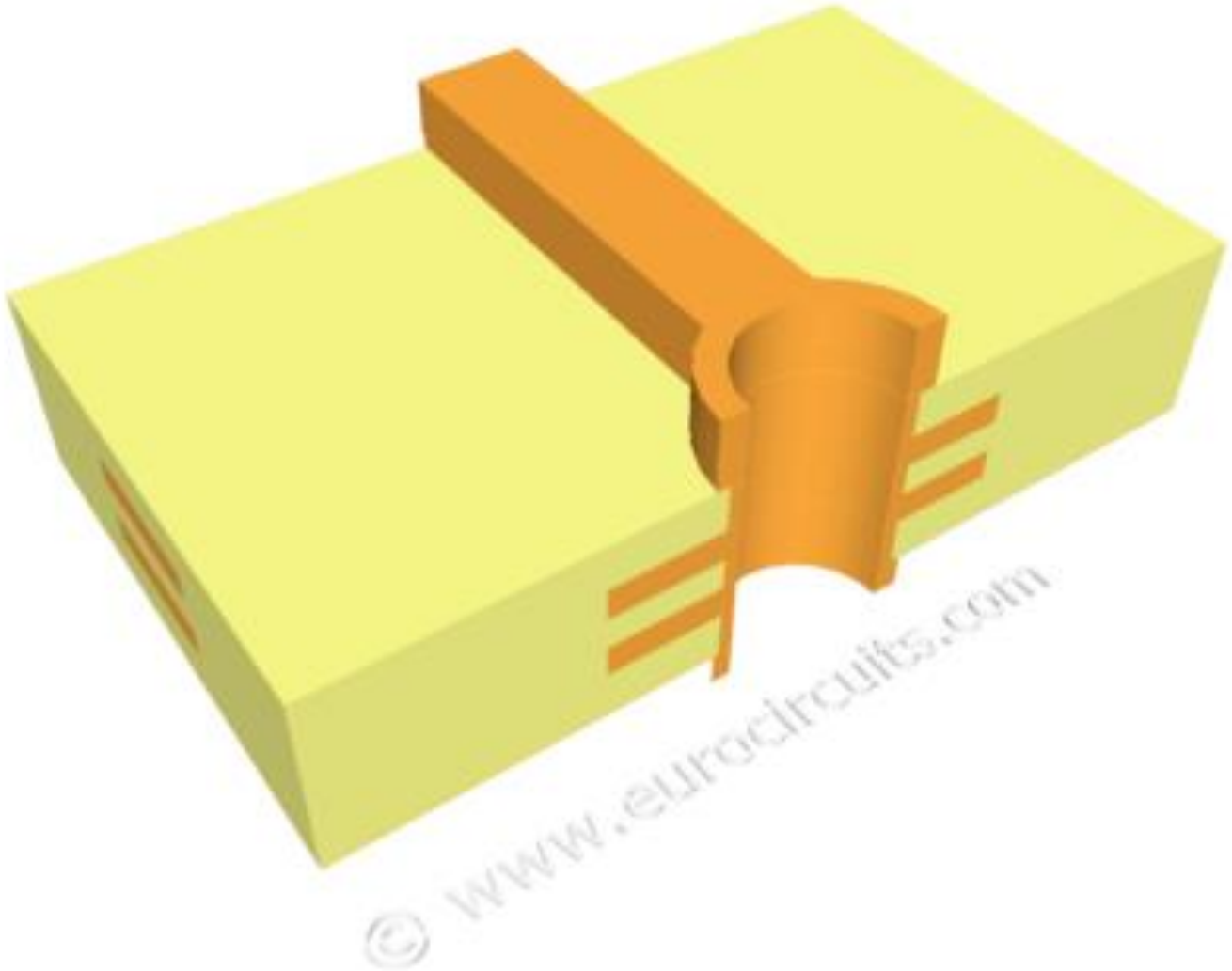
Etching photoresist to expose the copper



Removal of unwanted copper with alkaline solution

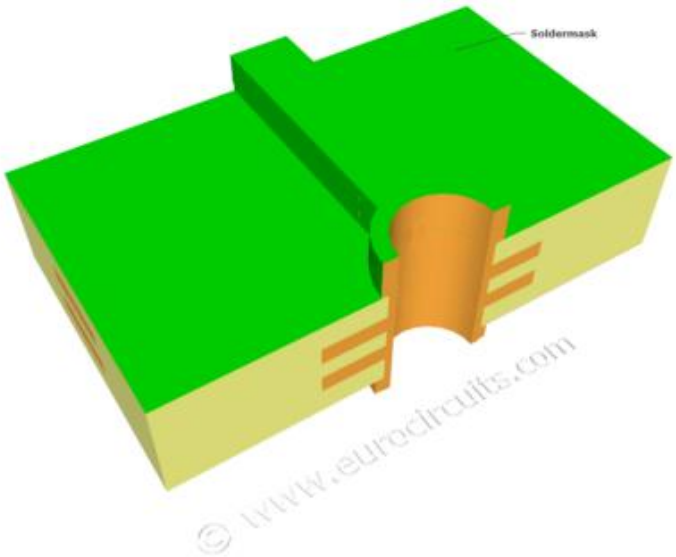


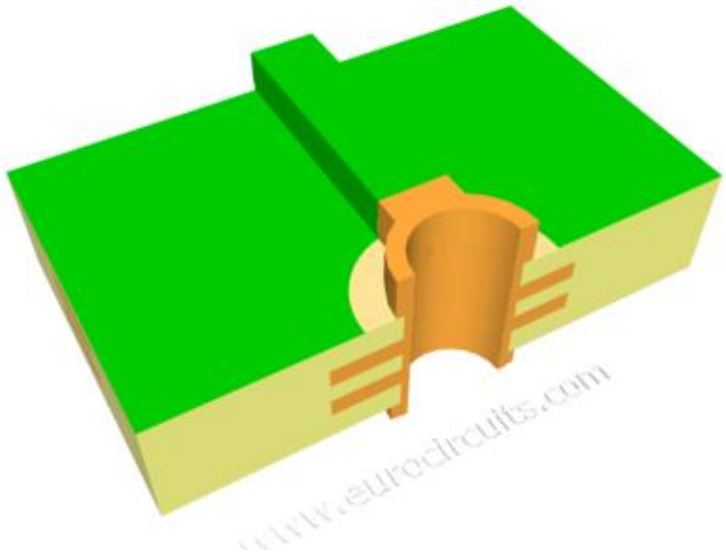
Remove the tin layer!



How to fabricate PCBs?

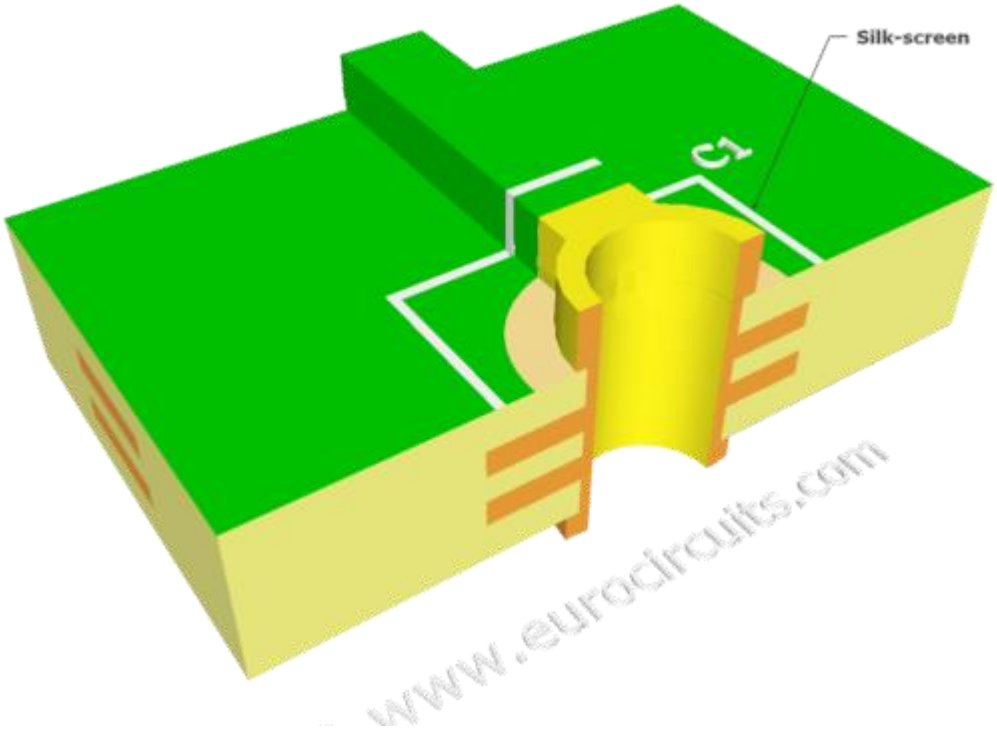
- Soldermask → To protect the copper surface and prevent solder shorting between components during assembly
- Coating machine simultaneously covers both sides of the panel with the epoxy soldermask ink
- Next the coated panels are imaged. The imaged panels are put on a conveyor out of the clean room and into the developer which strips off the unhardened and unwanted resist

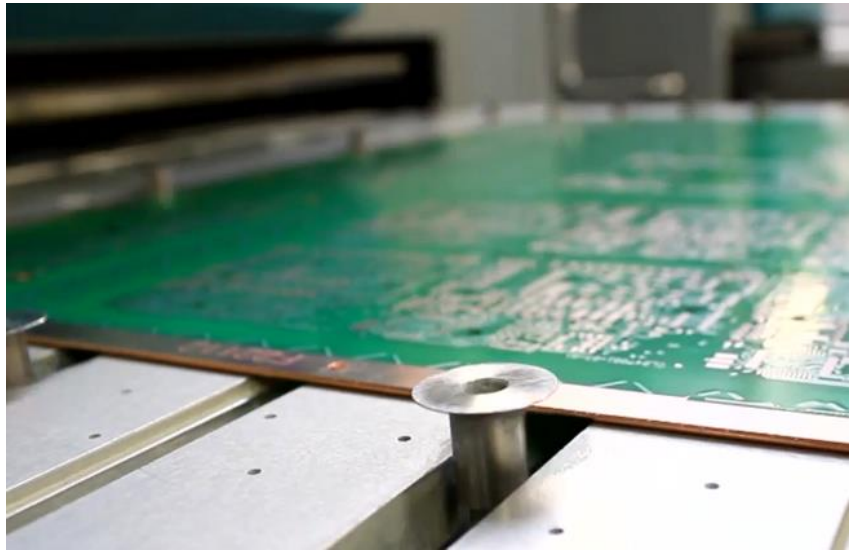




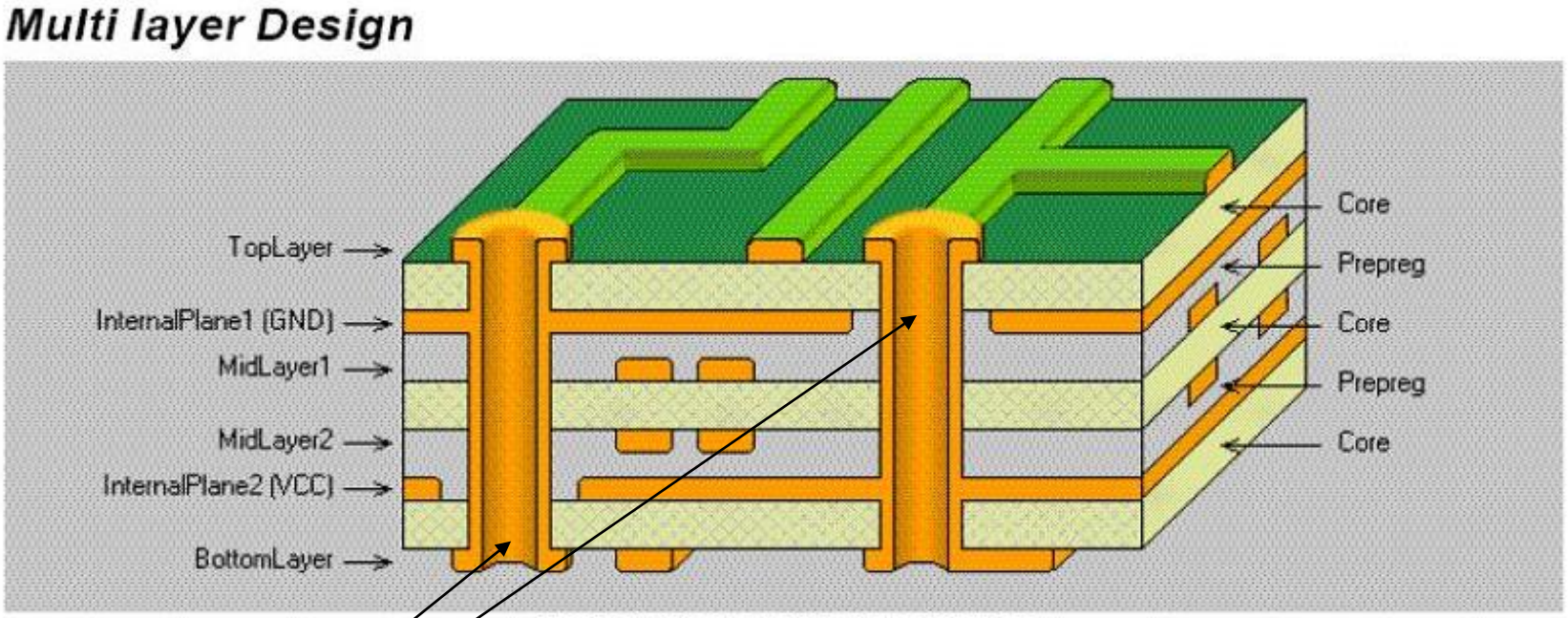
How to fabricate PCBs?

- Silk Screen → Most PCBs have a component legend to show which component goes where
- Ink-jet printers are used to image the legends direct from the board digital data





More complicated PCBs…



Plated VIAs

Sources

Part of the material (figures, text, …) included in these slides originates from the following sources, which were freely accessible on the internet at the time this presentation was created.

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The following texts have also been used to prepare this lecture:

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