

My Recent Experience Developing Open Hardware using KiCAD

A newcomer's journey from an idea to a layout

Carlos Henrique Craveiro Aquino Veras

University of São Paulo - São Carlos

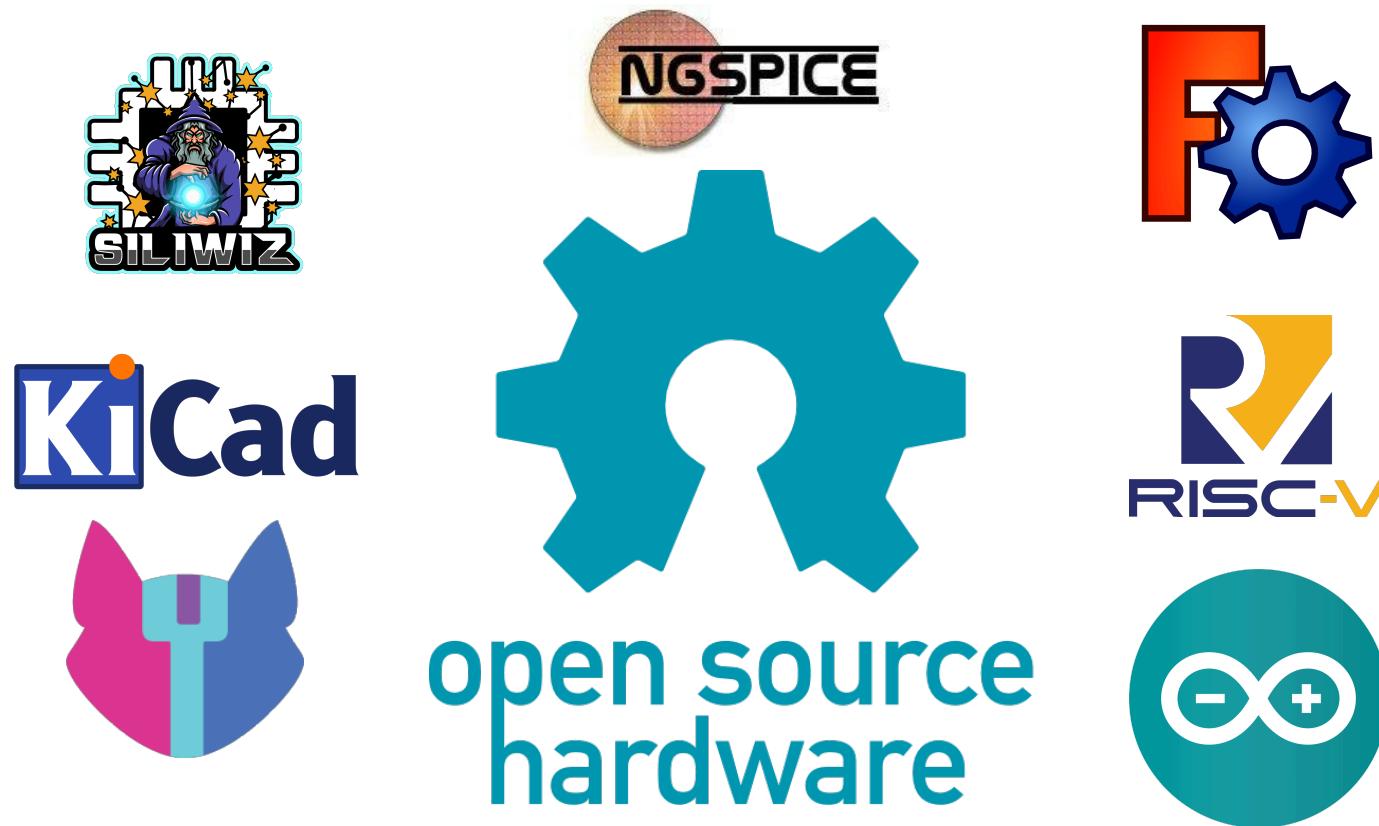
August 24, 2024

Who am I?

- Carlos Henrique Craveiro Aquino Veras
- Computer Engineering Undergrad Student
- FOSS Herald and Advocate
- Curious guy that loves to learn new things

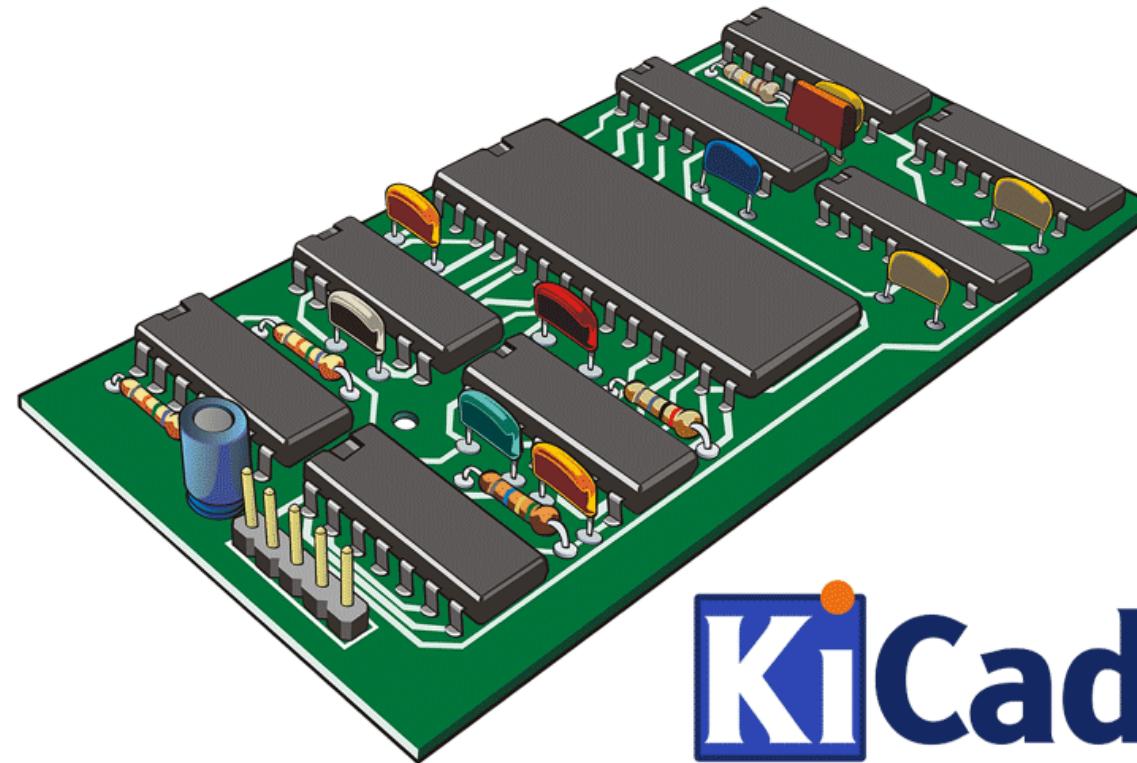


Open Source Hardware



And many many more...

Focus of the presentation



How it can be used to create amazing things!

The inspiration

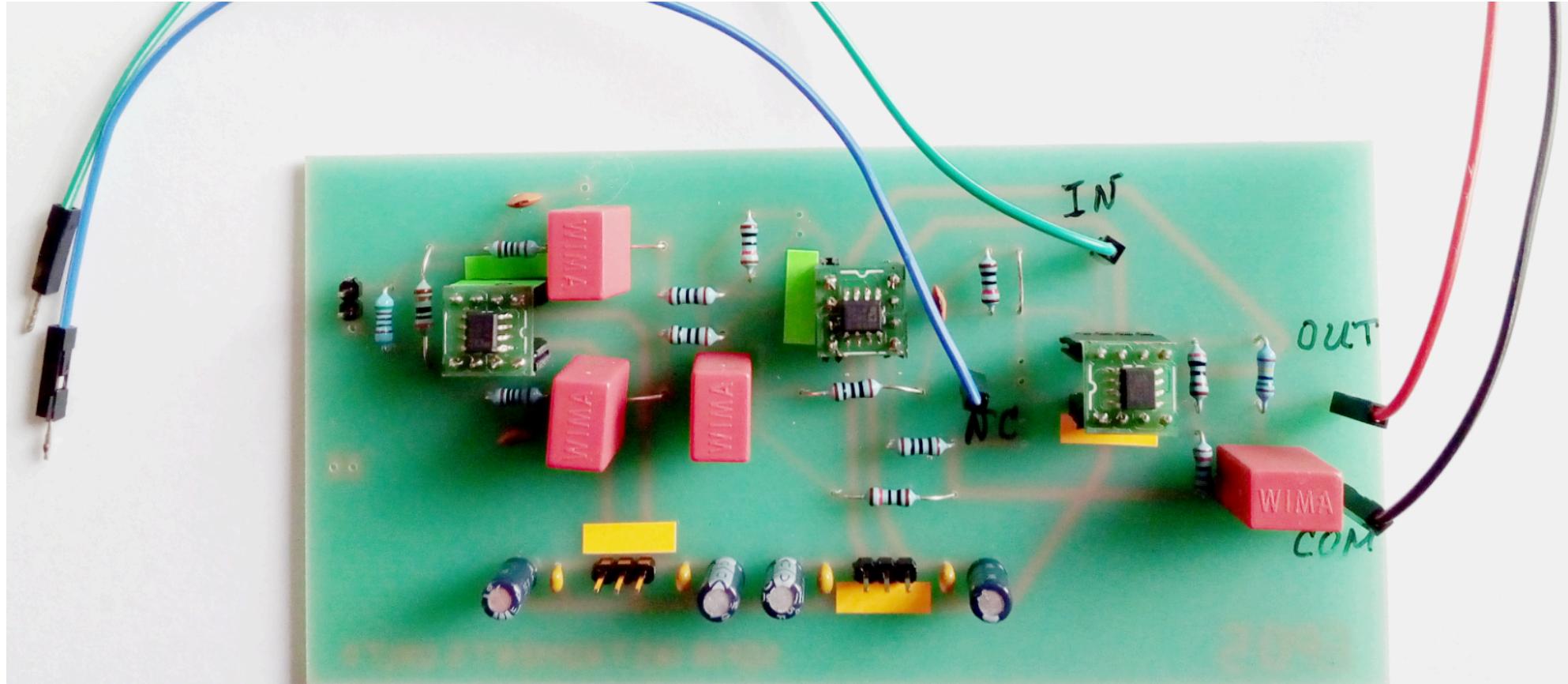
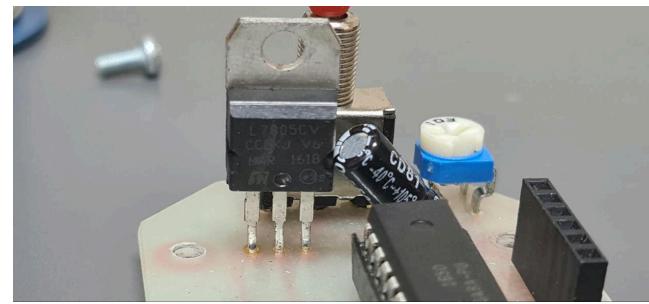


Figure 11: The Original board¹

When it all started?



Original Work

Measurement of the Boltzmann constant by Einstein. Problem of the 5-th Experimental Physics Olympiad. Sofia 9 December 2017

Todor M. Mishonov, Emil G. Petkov, Aleksander A. Stefanov, Aleksander P. Petkov*

Physics Faculty,

*St. Clement of Ohrid University at Sofia,
5 James Bourchier blvd, BG-1164 Sofia*

Iglika M. Dimitrova

Faculty of Chemical Technologies,

Department of Physical Chemistry,

*University of Chemical Technology and Metallurgy,
8, Kliment Ohridski blvd, BG-1756 Sofia*

Stojan G. Manolev†

Middle school Goce Delchev,

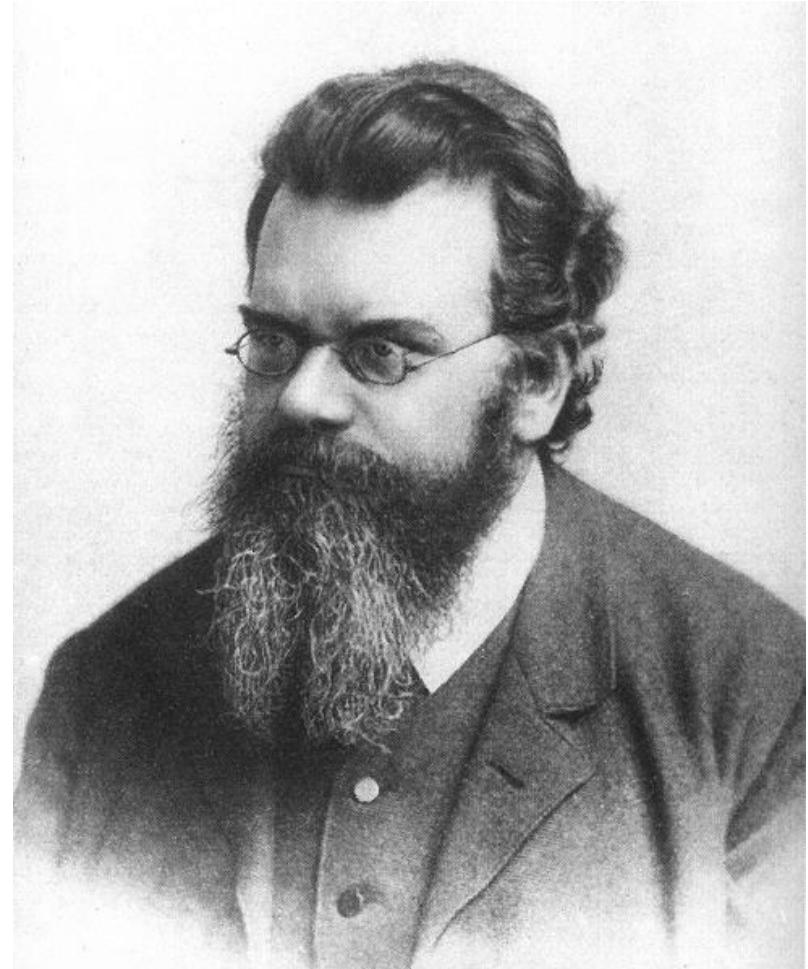
Purvomaiska str. 3,

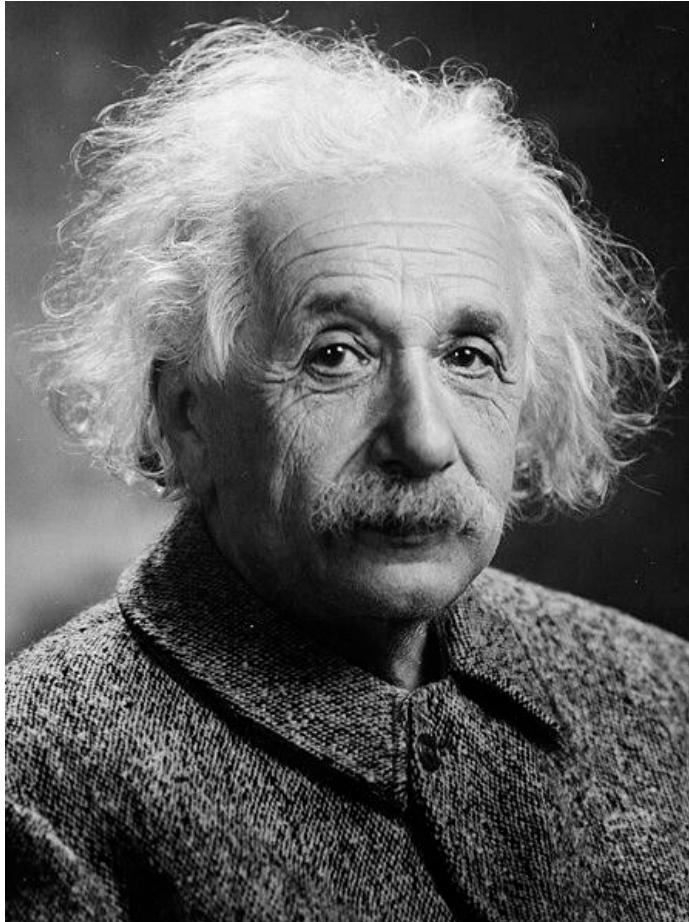
MKD-2460 Valandovo, R. Macedonia

And other authors...

The Boltzmann Constant

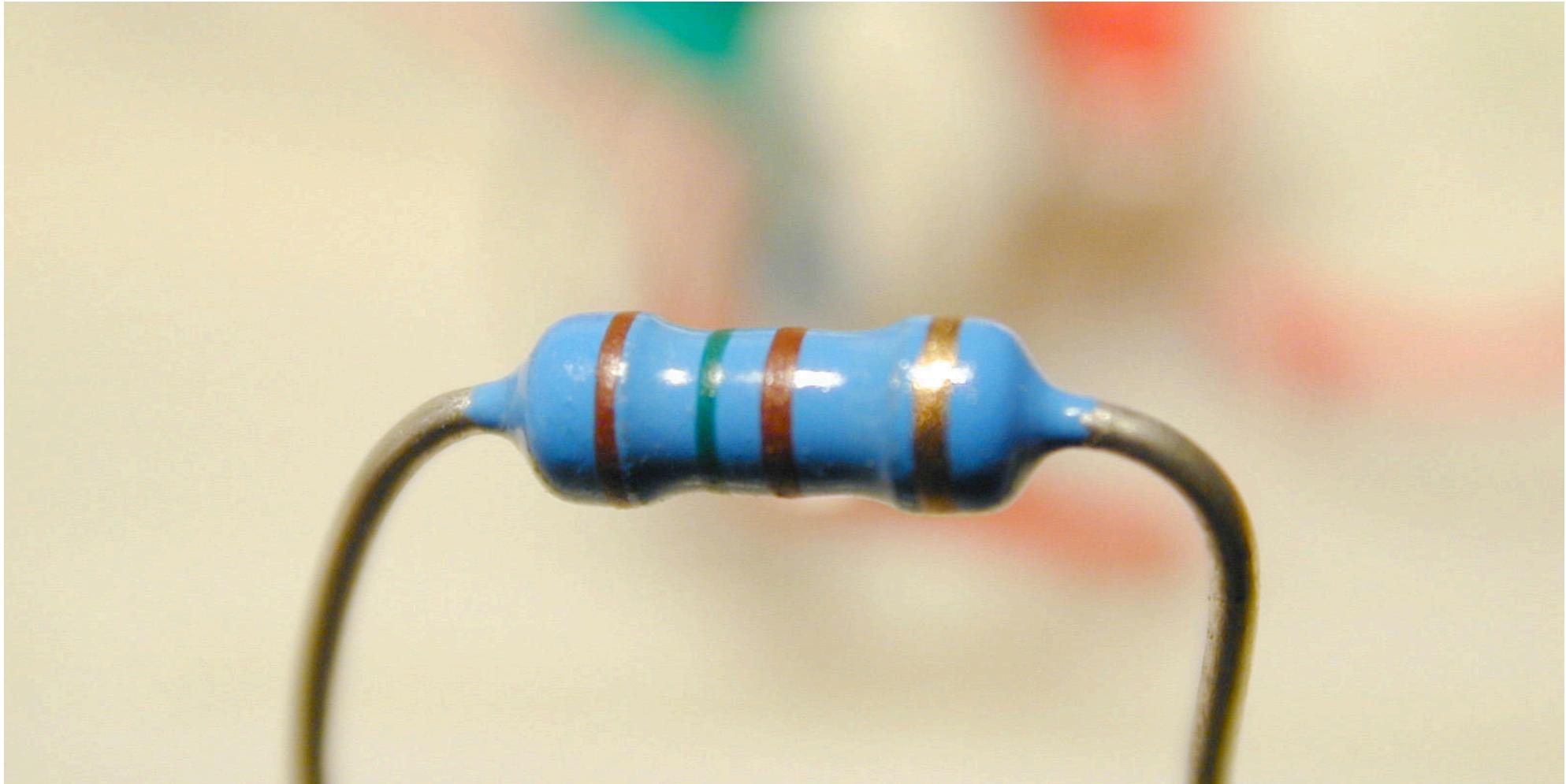
$$k_B = 1.380650 \cdot 10^{23} J.K^{-1}$$





Find k_B by examination of the mean
Thermal Energy¹!

The Noisy Element



Thermal Noise

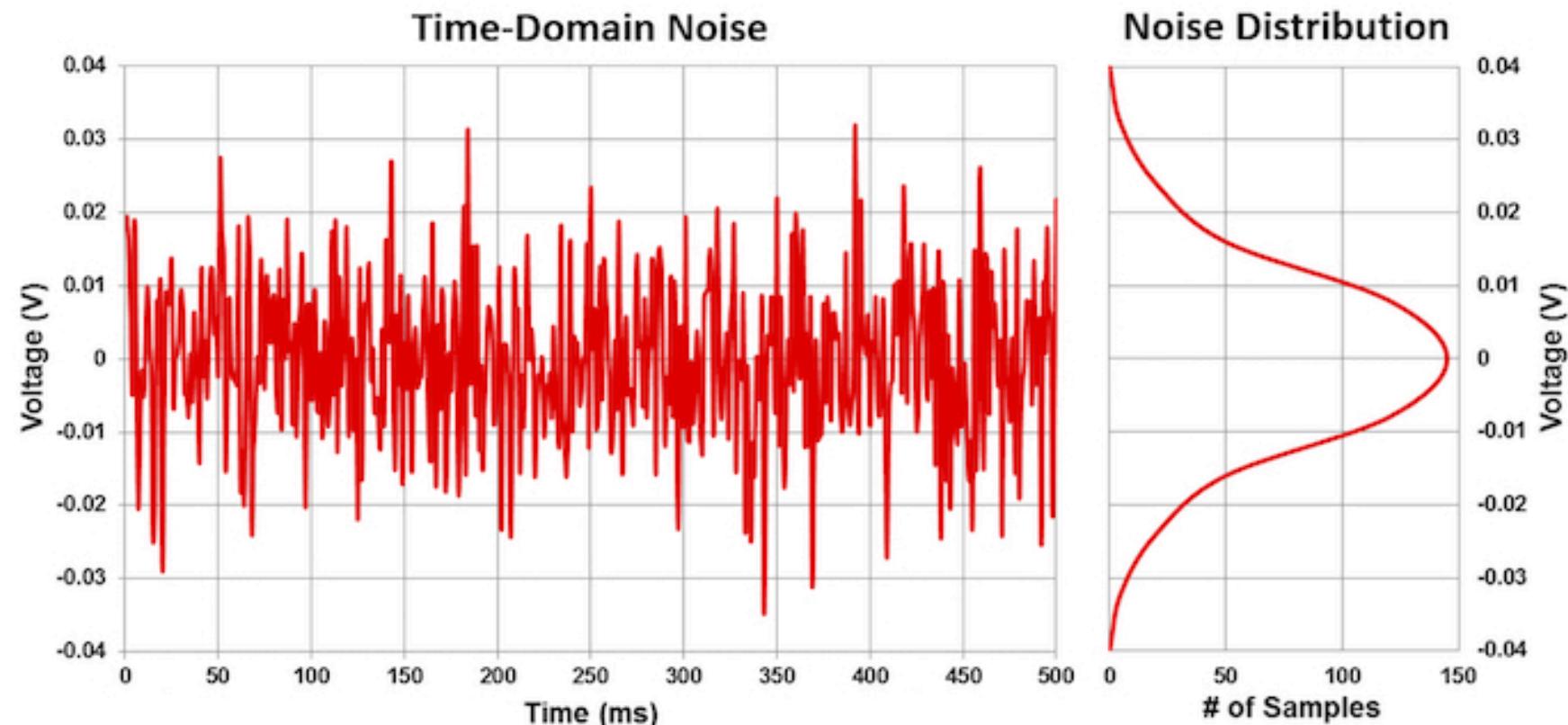
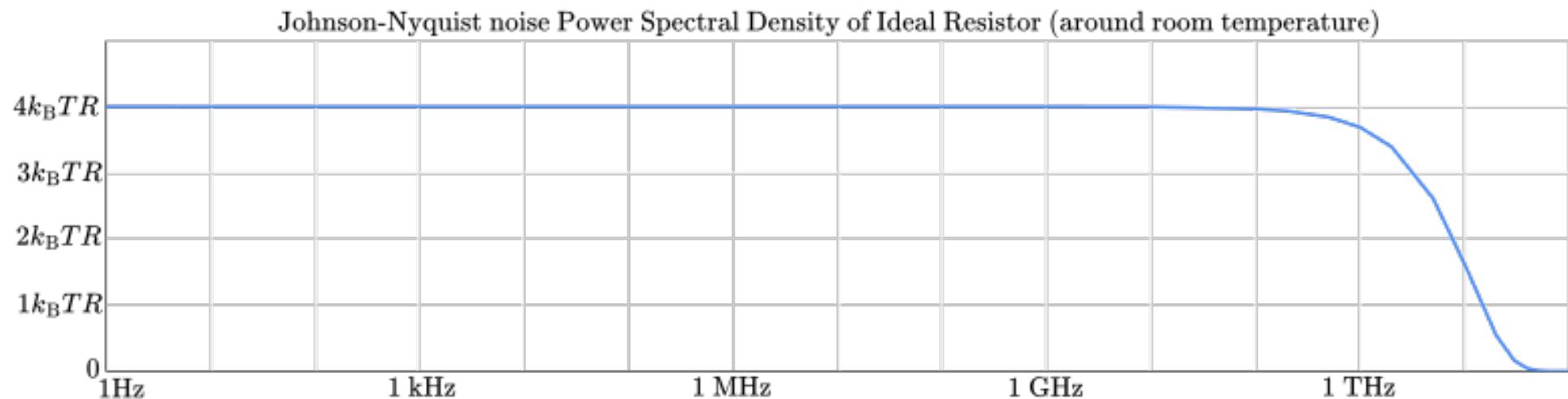


Figure 21: <https://www.nwengineeringllc.com/article/thermal-noise-in-communication-and-optical-systems.php>

Power Spectral Density

$$S_n(\omega)$$

Thermal Noise Source

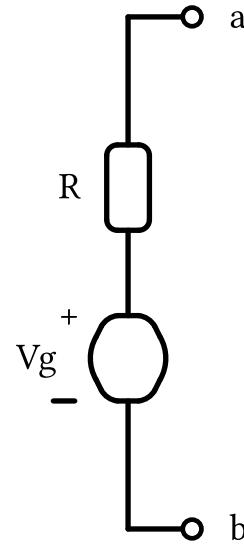


$$\overline{V_n^2} = 4k_B T R \Delta f$$

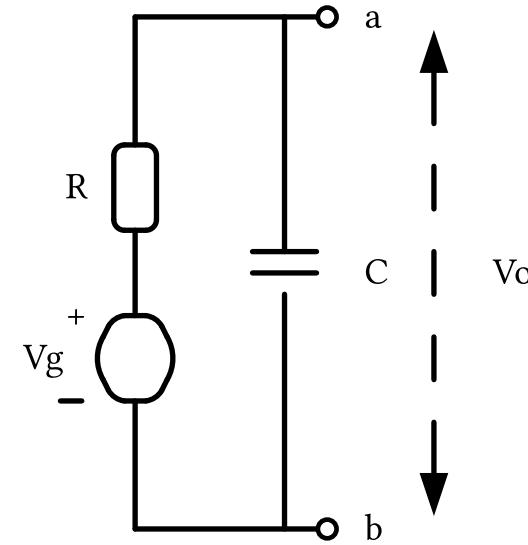
So V_n^2 depends of Δf and R ? What a Drama!

Signal Source²

$$S_n(\omega) = 4k_B T R$$

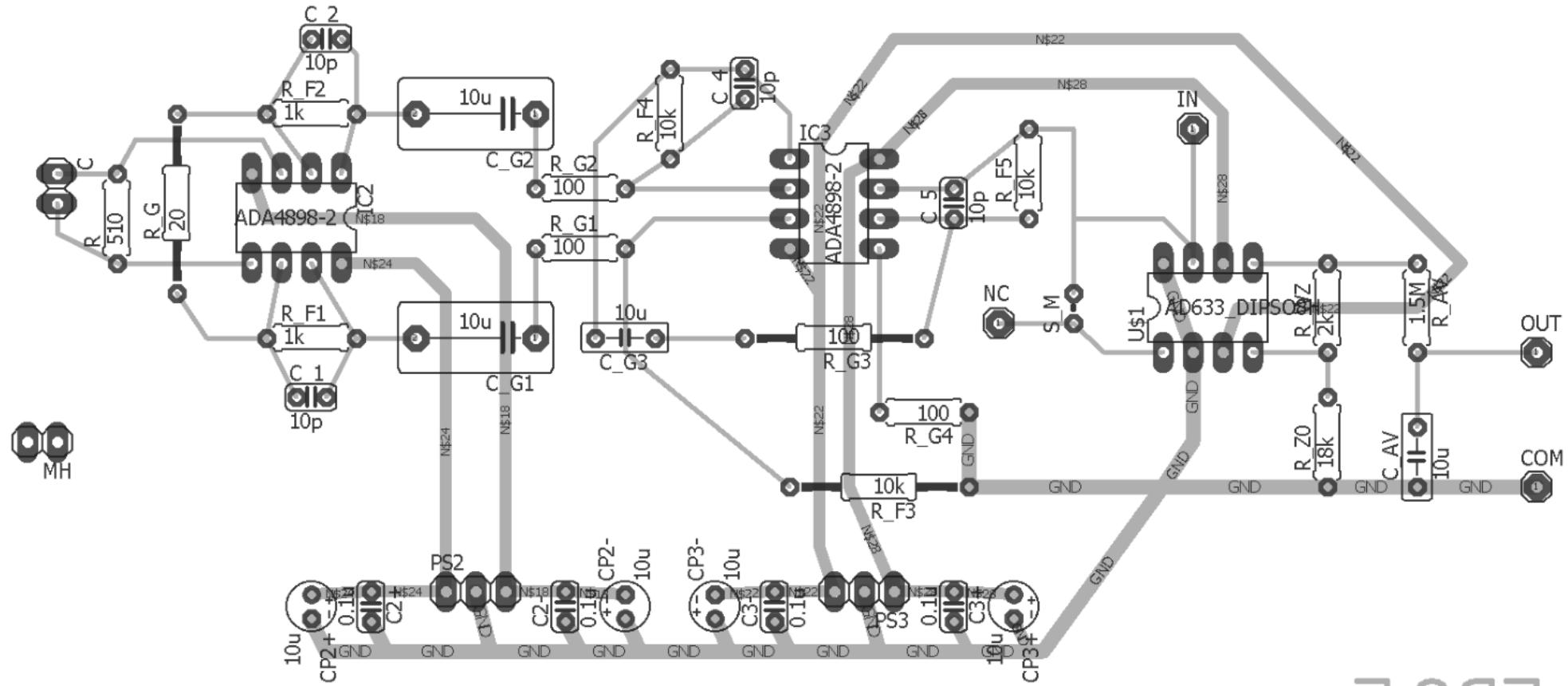


$$S_n(\omega) = |H(\omega)|^2 \cdot 4k_B T R$$



$$\overline{V_o}^2 = \frac{k_B T}{C}$$

Original Layout



SOFIA INSTRUMENTS LTD

EPO

KiCad EDA

A Cross Platform and Open Source
Electronics Design Automation Suite

 Documentation

 Download   

 See what's new



Schematic Editor
Edit the project schematic



Symbol Editor
Edit global and/or project schematic symbol libraries



PCB Editor
Edit the project PCB design



Footprint Editor
Edit global and/or project PCB footprint libraries



Gerber Viewer
Preview Gerber files



Image Converter
Convert bitmap images to schematic symbols or PCB footprints



Calculator Tools
Show tools for calculating resistance, current capacity, etc.

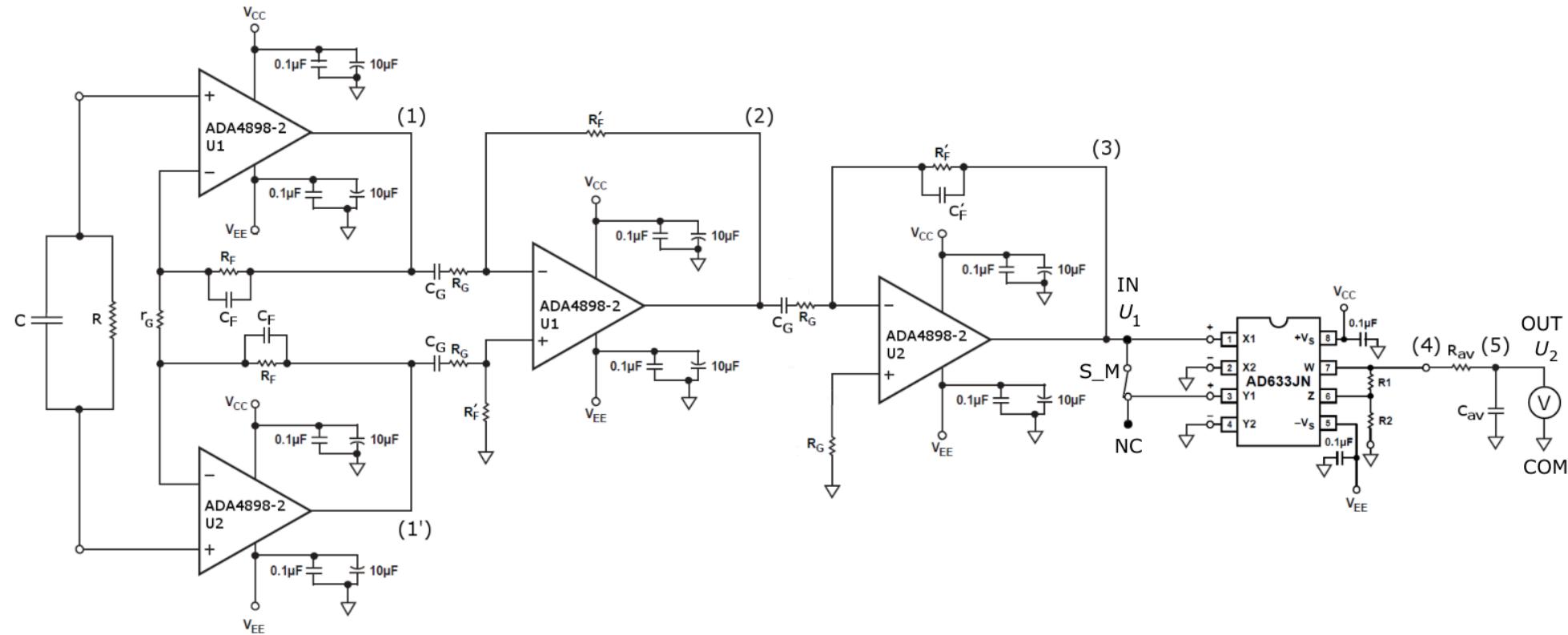


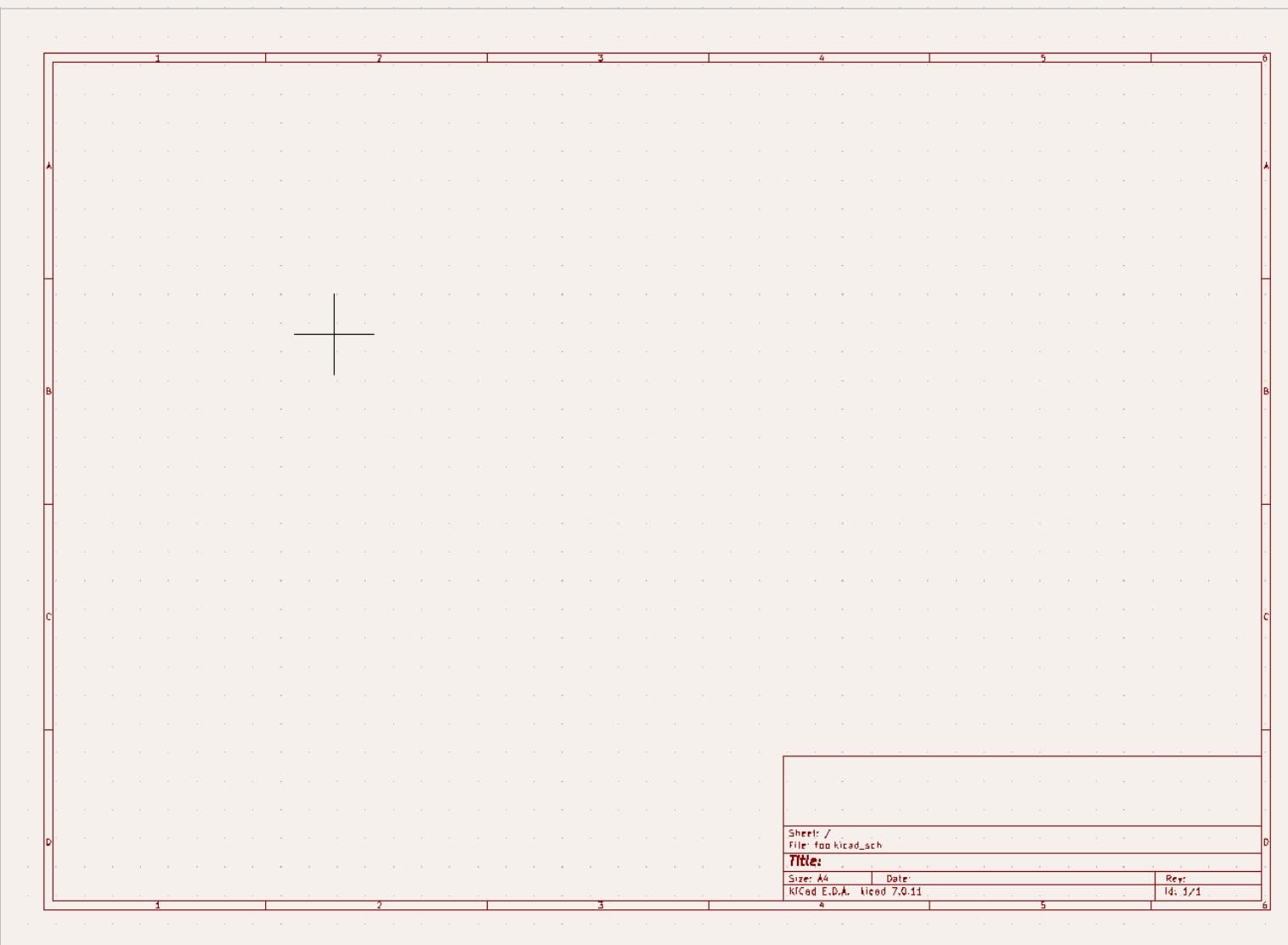
Drawing Sheet Editor
Edit drawing sheet borders and title blocks for use in schematics and PCB designs



Plugin and Content Manager
Manage downloadable packages from KiCad and 3rd party repositories

Original Schematics





Sheet: /
File: foo.kicad_sch

Title:

Size: A4
KICad E.D.A. kicad 7.0.11

Date:
Rev:
14: 1/1



Choose Symbol (20659 items loaded)

opamp

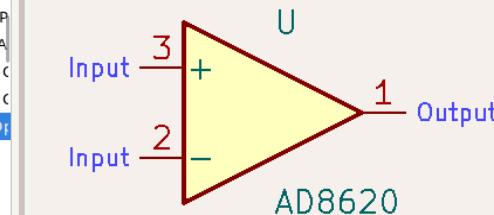
Item	Description
AD8021AR	Operational Amplifier, 4.5-24V single/dual supply, low noise, high speed, SOIC-8
AD8021ARM	Operational Amplifier, 4.5-24V single/dual supply, low noise, high speed, MSOP-8
AD8603	Precision Micropower, Low Noise CMOS, Rail-to-Rail Input/Output Operational Amplifier
AD8610xR	Single Precision, Very Low Noise, Low Input Bias Current, Wide Bandwidth JFET Operational Amplifier
AD8610xRM	Single Precision, Very Low Noise, Low Input Bias Current, Wide Bandwidth JFET Operational Amplifier
AD8620	Dual Precision, Very Low Noise, Low Input Bias Current, Wide Bandwidth JFET Operational Amplifier
Unit A	
Unit B	
Unit C	
▶ AD8620xRM	Dual Precision, Very Low Noise, Low Input Bias Current, Wide Bandwidth JFET Operational Amplifier
AD8655	Single Low Noise, Precision CMOS Amplifier
▶ AD8656	Dual Low Noise, Precision CMOS Amplifier
▶ AD8676xR	Dual operational amplifier, Ultra-precision, 36V, Rail-to-rail output, SOIC-8
▶ ADA4075-2	Ultralow Noise Amplifier at Lower Power, SOIC-8/LFCSP-8
ADA4077-1xR	4MHz, 7nV/sqrtHz, Low Offset and Drift, High Precision Amplifier, SOIC-8
ADA4077-1xRM	4MHz, 7nV/sqrtHz, Low Offset and Drift, High Precision Amplifier, MSOP-8
▶ ADA4084-4xCP	30V Quad Low Noise, Rail-to-Rail Input/Output, Low Power Operational Amplifiers
ADA4530-1	Femtoampere Input Bias Current Electrometer Amplifier, SOIC-8
ADA4610-1xR	Low Noise, Precision, Rail-to-Rail Output, JFET Single Op Amp, SOIC-8

AD8620
Derived from LM2904 (Dual Operational Amplifiers, DIP-8/SOIC-8/TSSOP-8/VSSOP-8)
Dual Precision, Very Low Noise, Low Input Bias Current, Wide Bandwidth JFET Operational Amplifiers, SOIC-8
Keywords: dual opamp

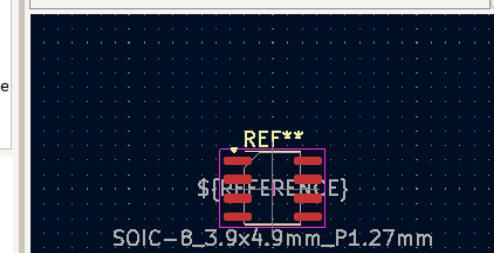
Reference U?
Footprint Package_SO:SOIC-8_3.9x4.9mm_P1.27mm

Select with Browser Place repeated copies Place all units

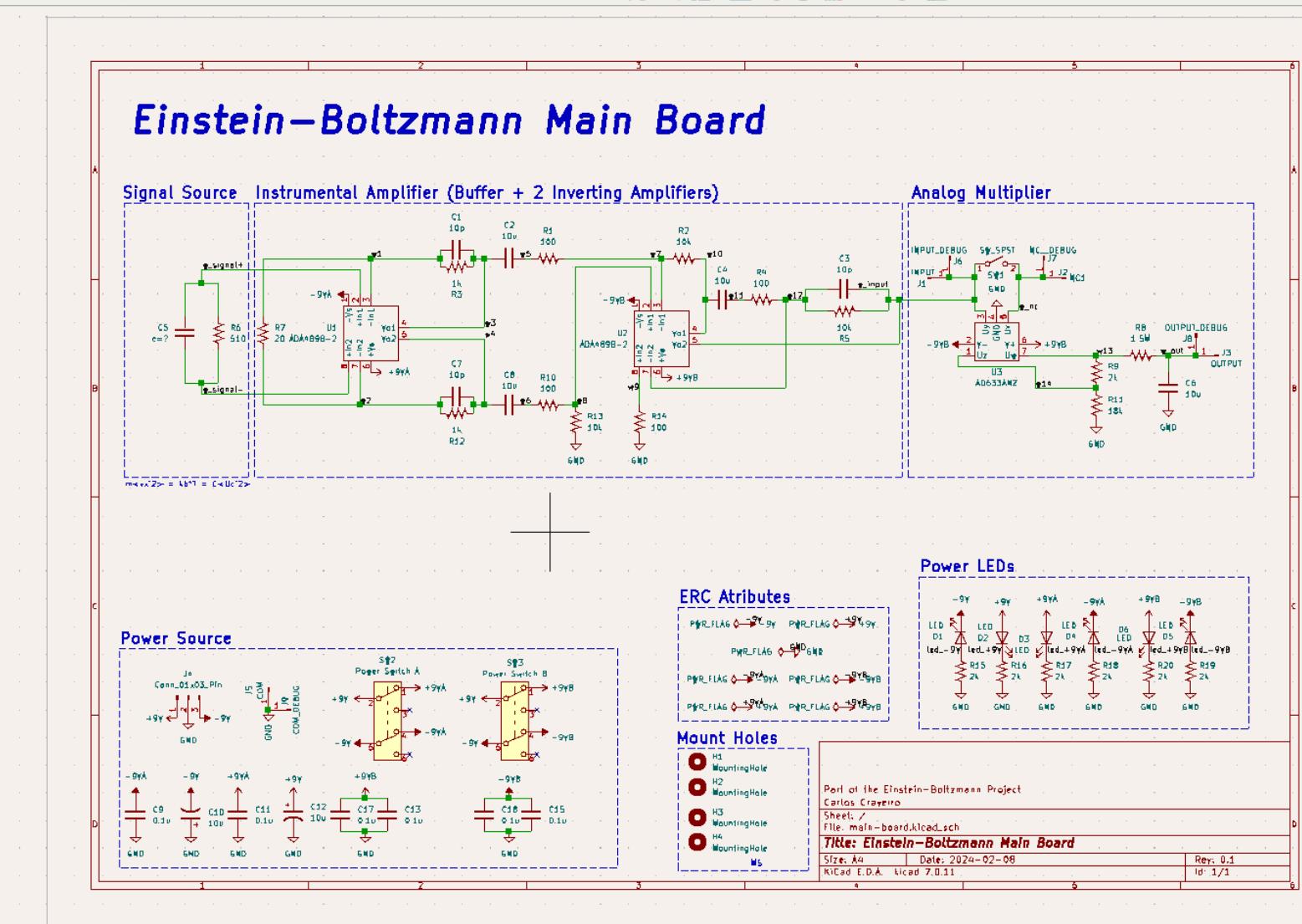
Cancel **OK**



[Default] Package_SO:SOIC-8_3.9x4.9mm_P1.27mm

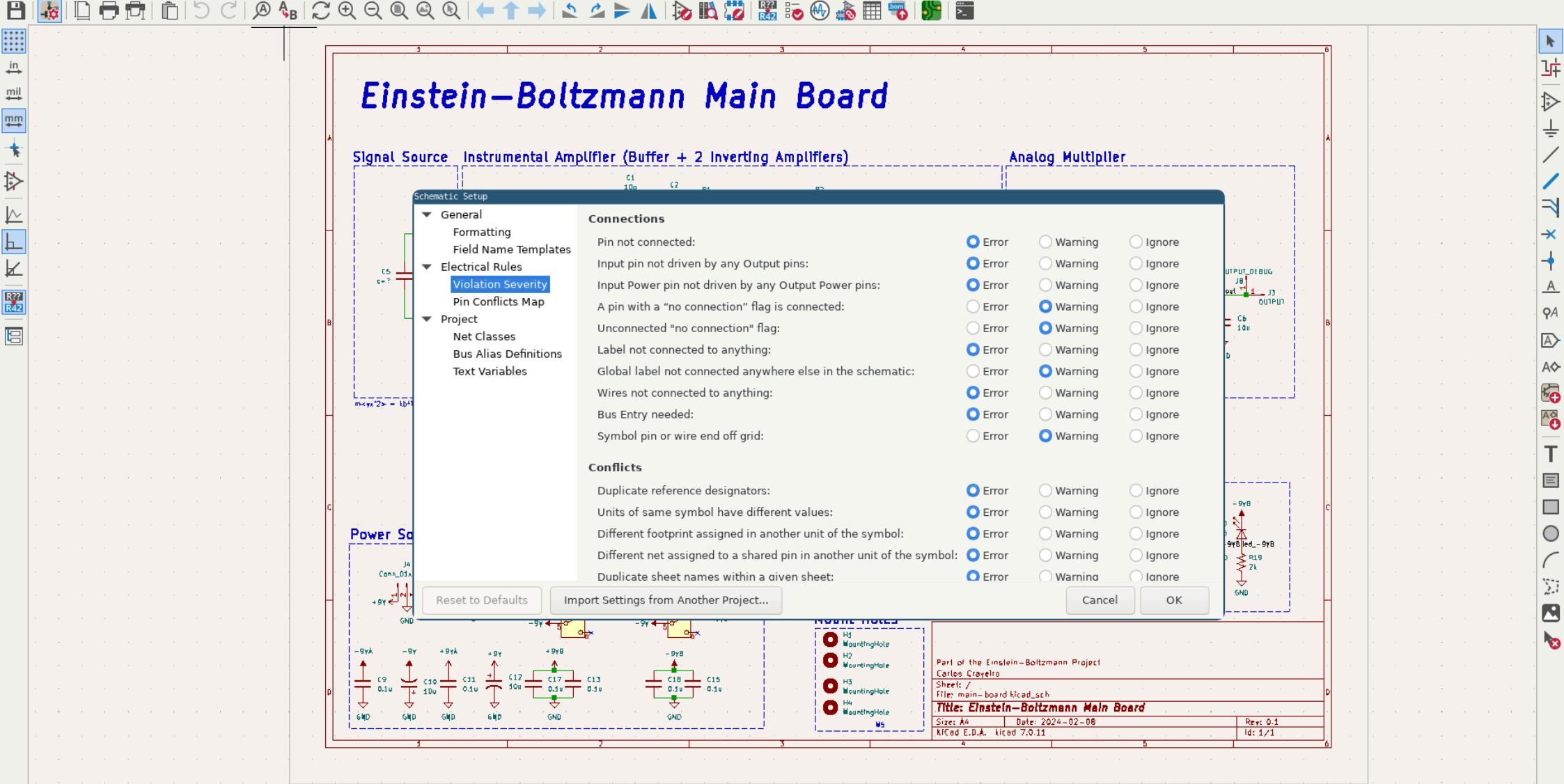


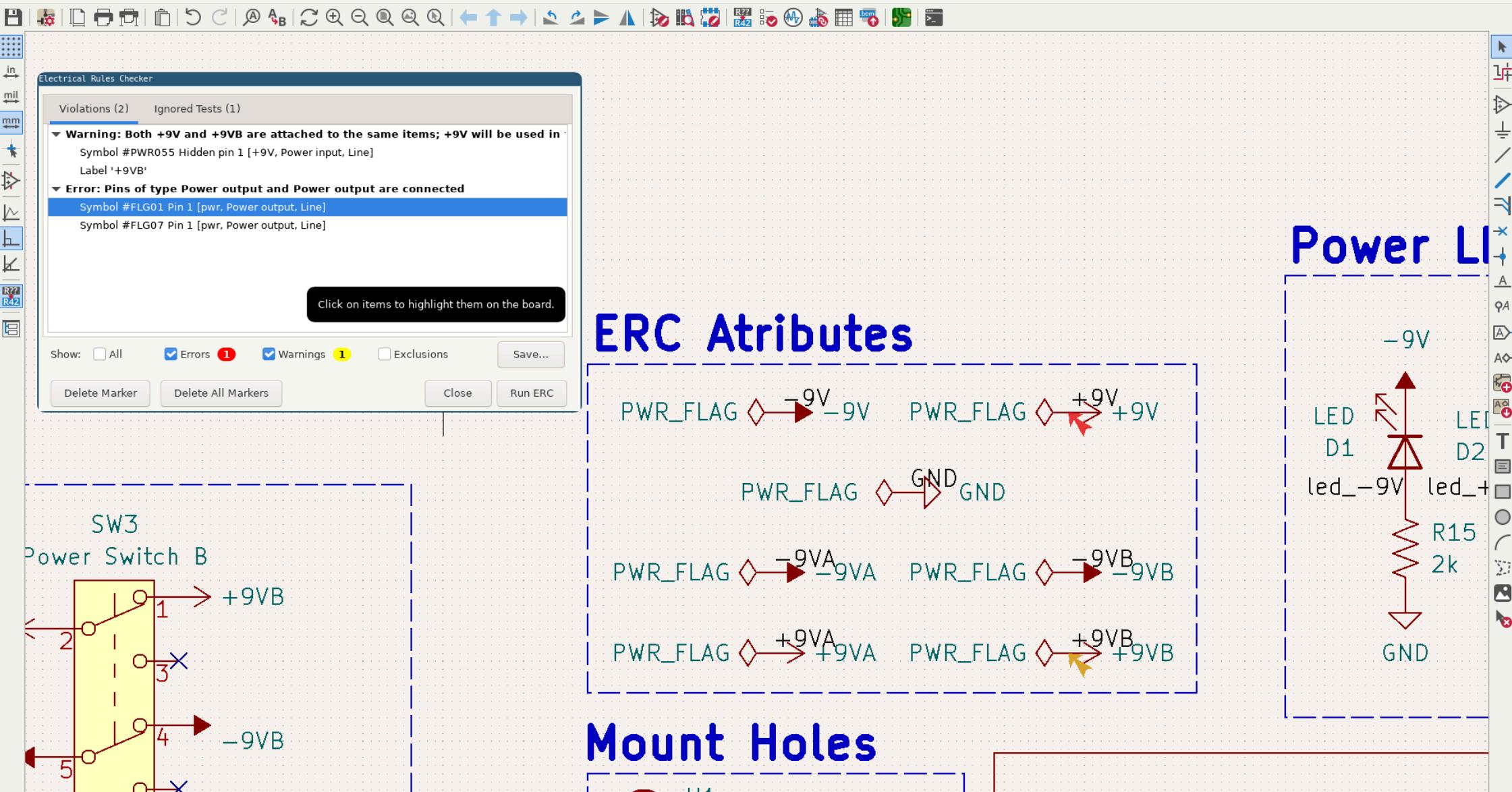
Title: Size: A4 Date: Rev: KICad EDA Licenced 7.0.11 14. 1/1

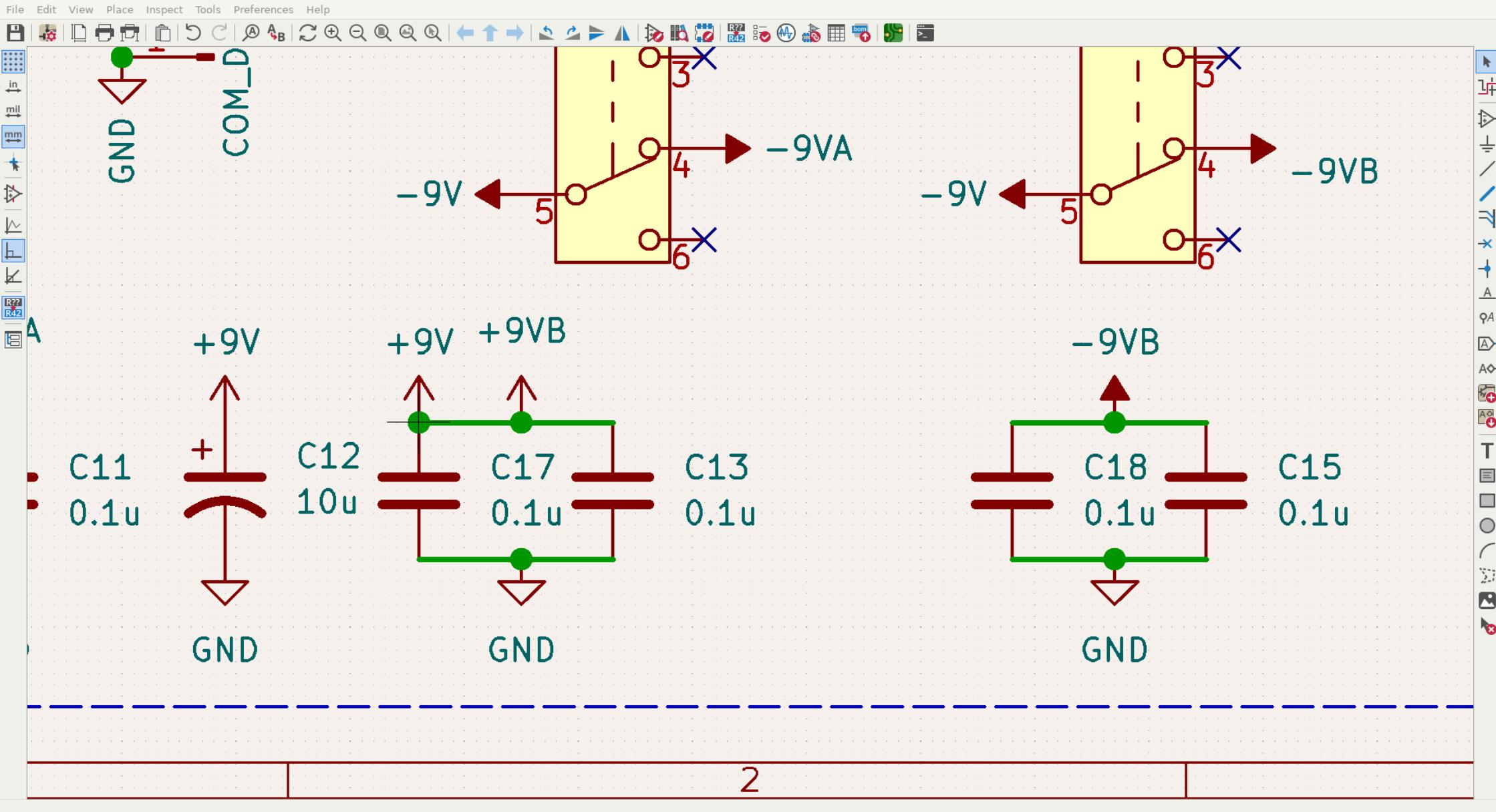


Electric Rule Checker

- Correctness of power and ground connections
- Problems with the SPICE simulation models
- Unconnected inputs or shorted outputs
- Conflicting information on schematic

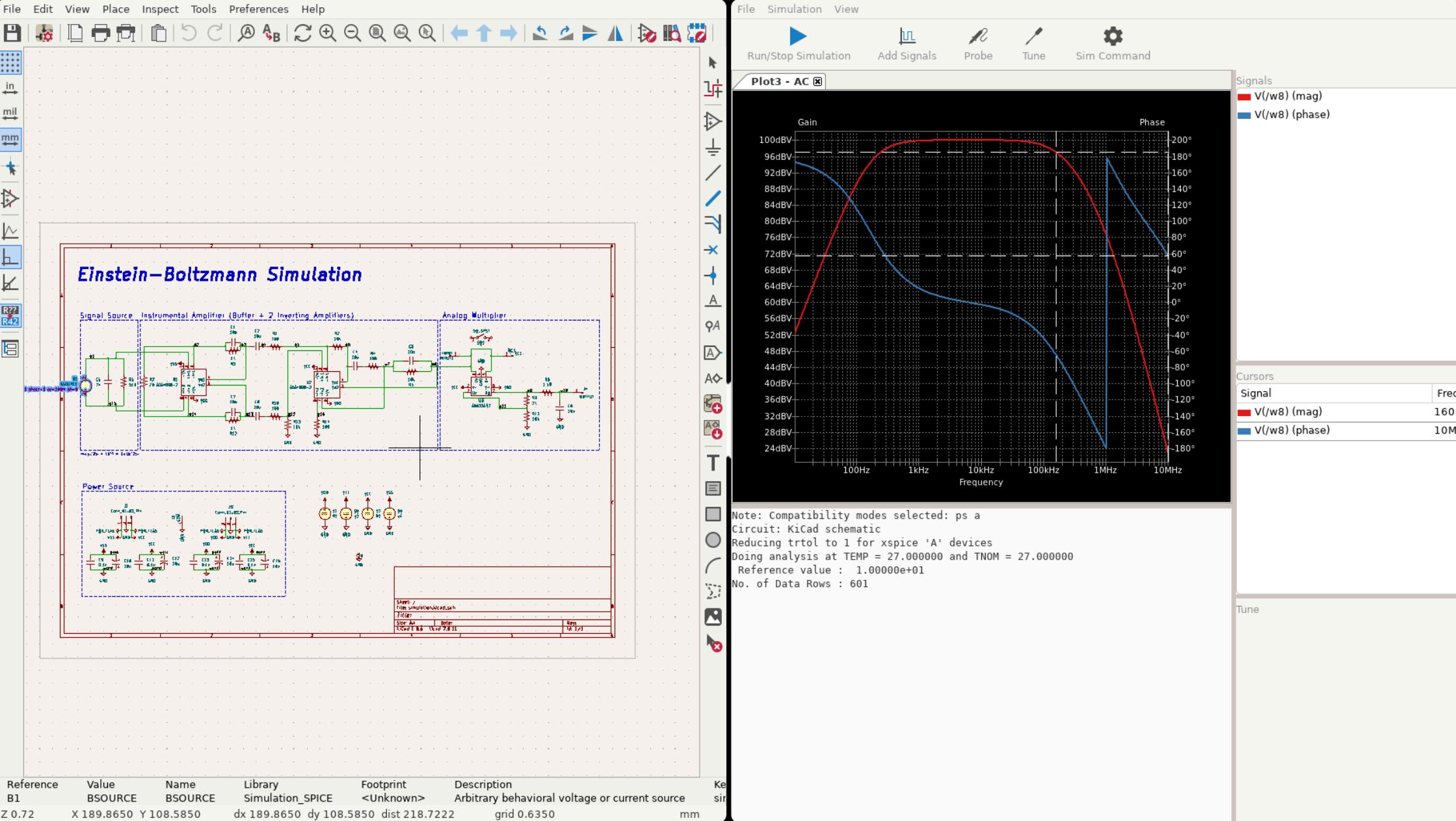






Simulation

- Verify the theoretical behaviour of the board
- KiCAD natively integrates simulation capabilities
- Uses NGSpice as the simulation engine
- Provides a variety of simulation types (DC Analysis, AC, Op, ...)





Track: use netclass width

Via: use netclass sizes

Grid: 0.0100 mm (0.0004 in)

Zoom 2.20



Layout



Pads 136 Vias 317 Track Segments 209 Nets 36 Unrouted 0

Z 2.19

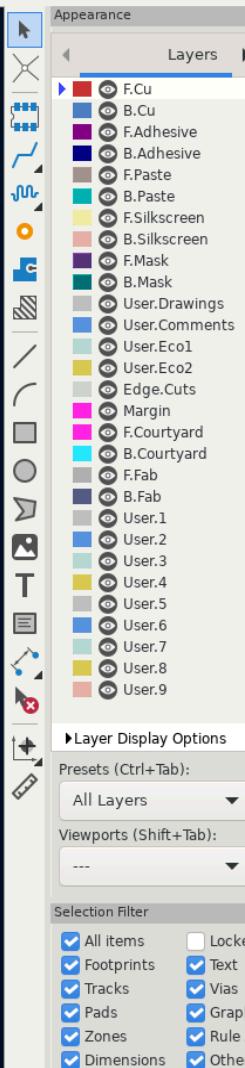
X 154.6200 Y 106.7400

dx 154.6200 dy 106.7400 dist 187.8850

grid X 0.0100 Y 0.0100

mm

Select item(s)





Track: use netclass width Via: use netclass sizes Grid: 0.0100 mm (0.0004 in) Zoom 2.20

F.Cu (PgUp)

Appearance

Layers

- F.Cu
- B.Cu
- F.Adhesive
- B.Adhesive
- F.Paste
- B.Paste
- F.Silkscreen
- B.Silkscreen
- F.Mask
- B.Mask
- User.Drawings
- User.Comments
- User.Eco1
- User.Eco2
- Edge.Cuts
- Margin
- F.Courtyard
- B.Courtyard
- F.Fab
- B.Fab
- User.1
- User.2
- User.3
- User.4
- User.5
- User.6
- User.7
- User.8
- User.9

Layer Display Options

Presets (Ctrl+Tab): All Layers

Viewports (Shift+Tab): ---

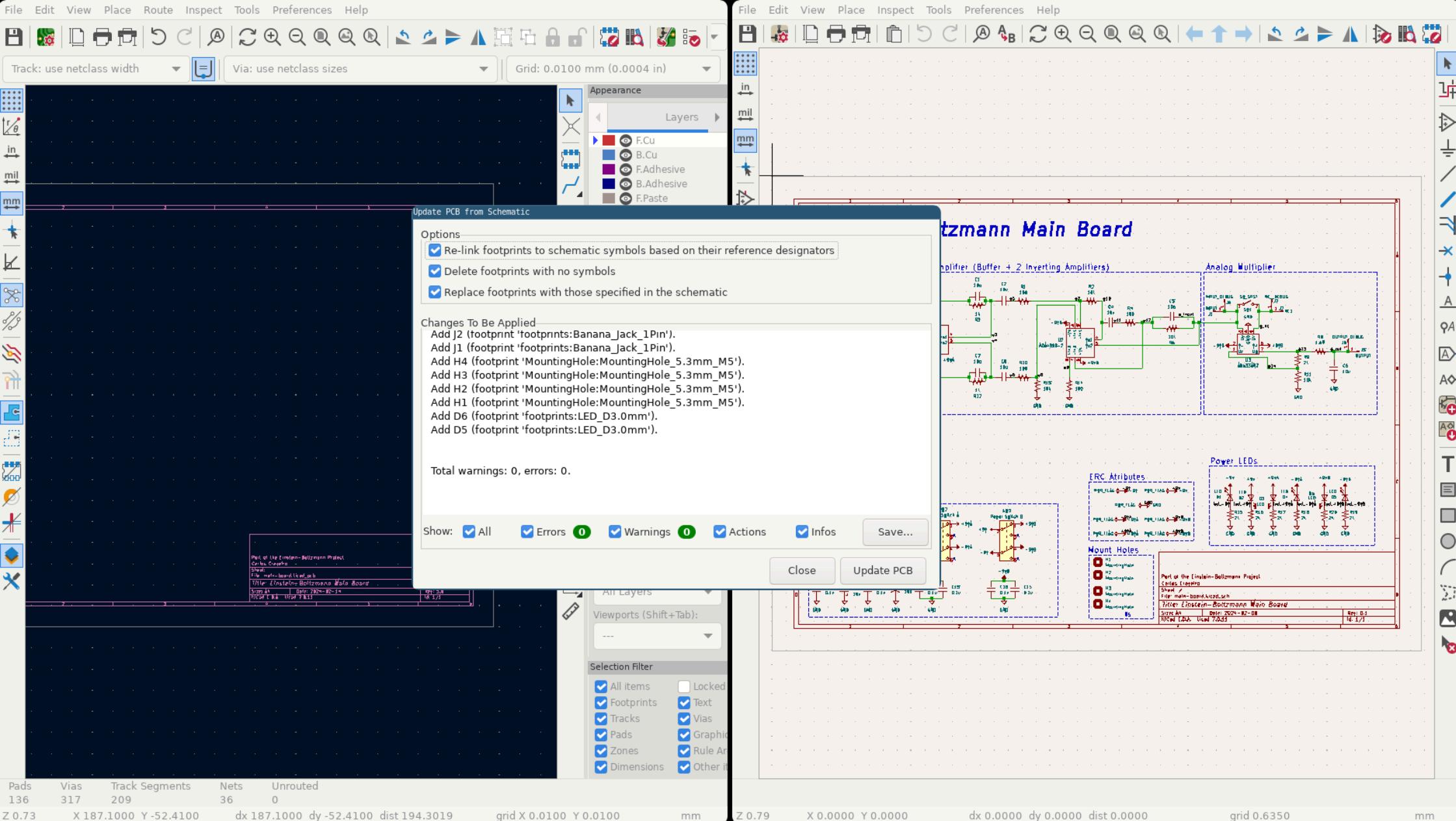
Selection Filter

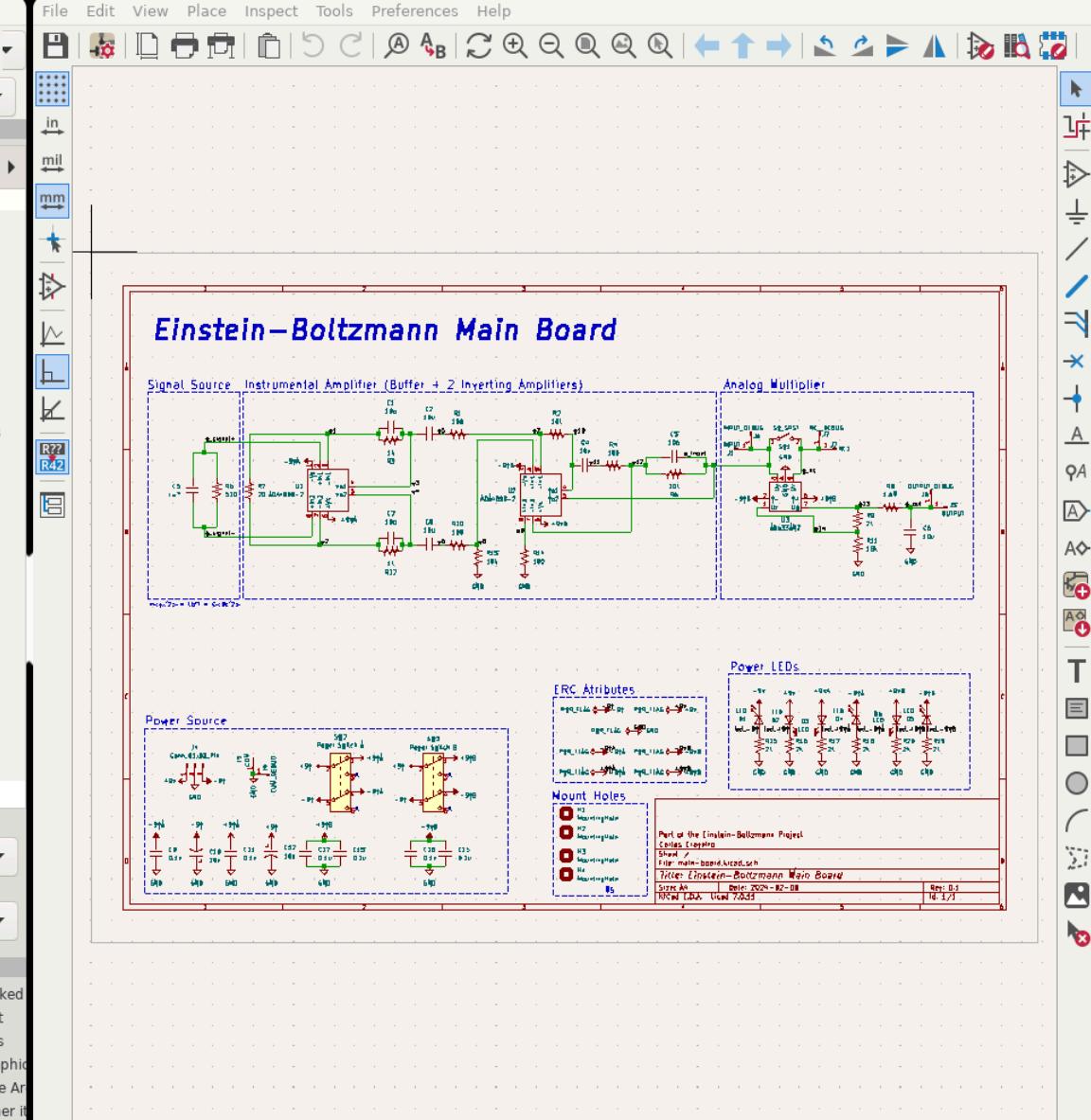
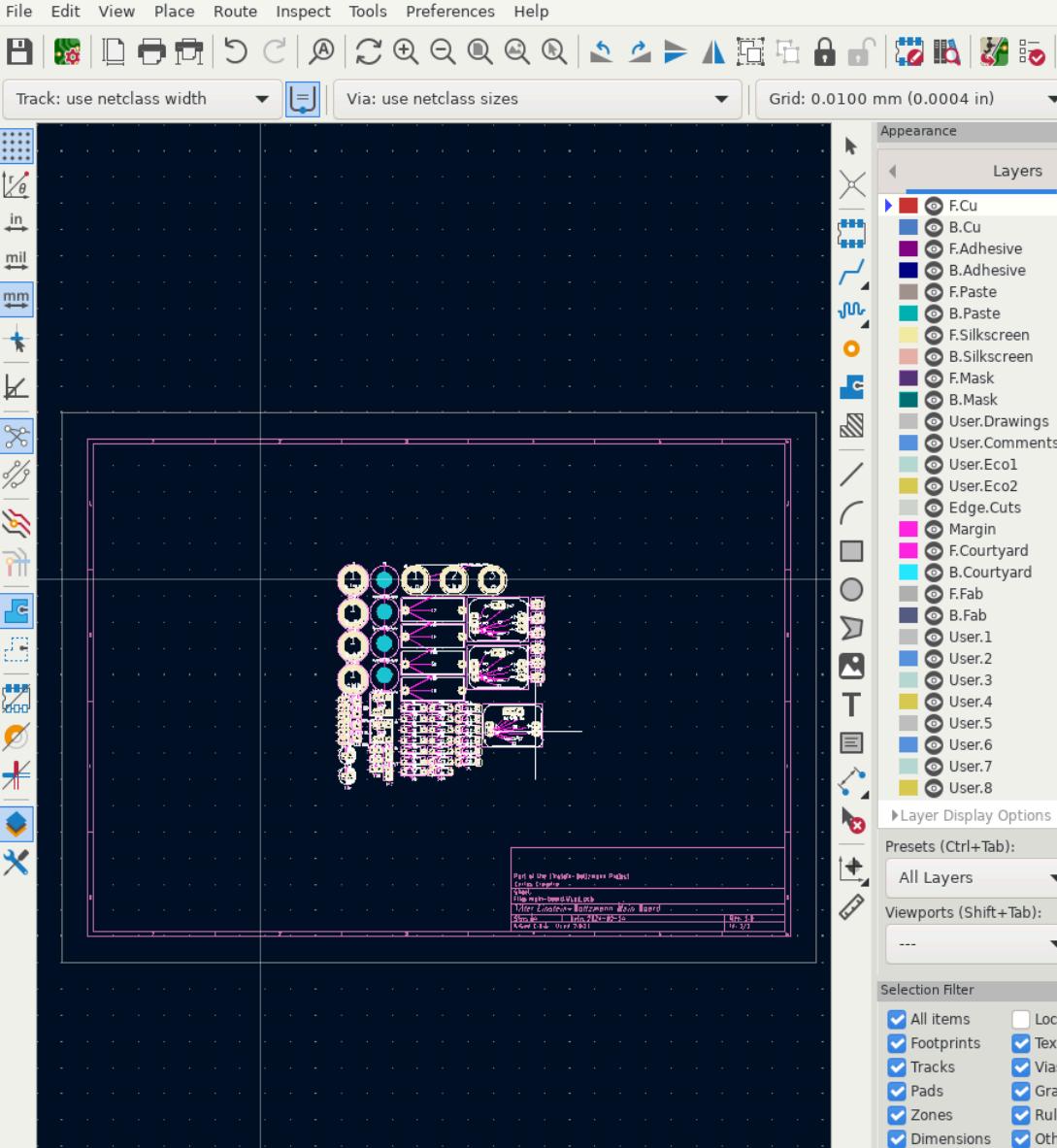
All items	Locked
<input checked="" type="checkbox"/>	<input type="checkbox"/>
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

Pads Vias Track Segments Nets Unrouted

136 317 209 36 0

Z 2.19 X 154.6200 Y 106.7400 dx 154.6200 dy 106.7400 dist 187.8850 grid X 0.0100 Y 0.0100 mm Select item(s)





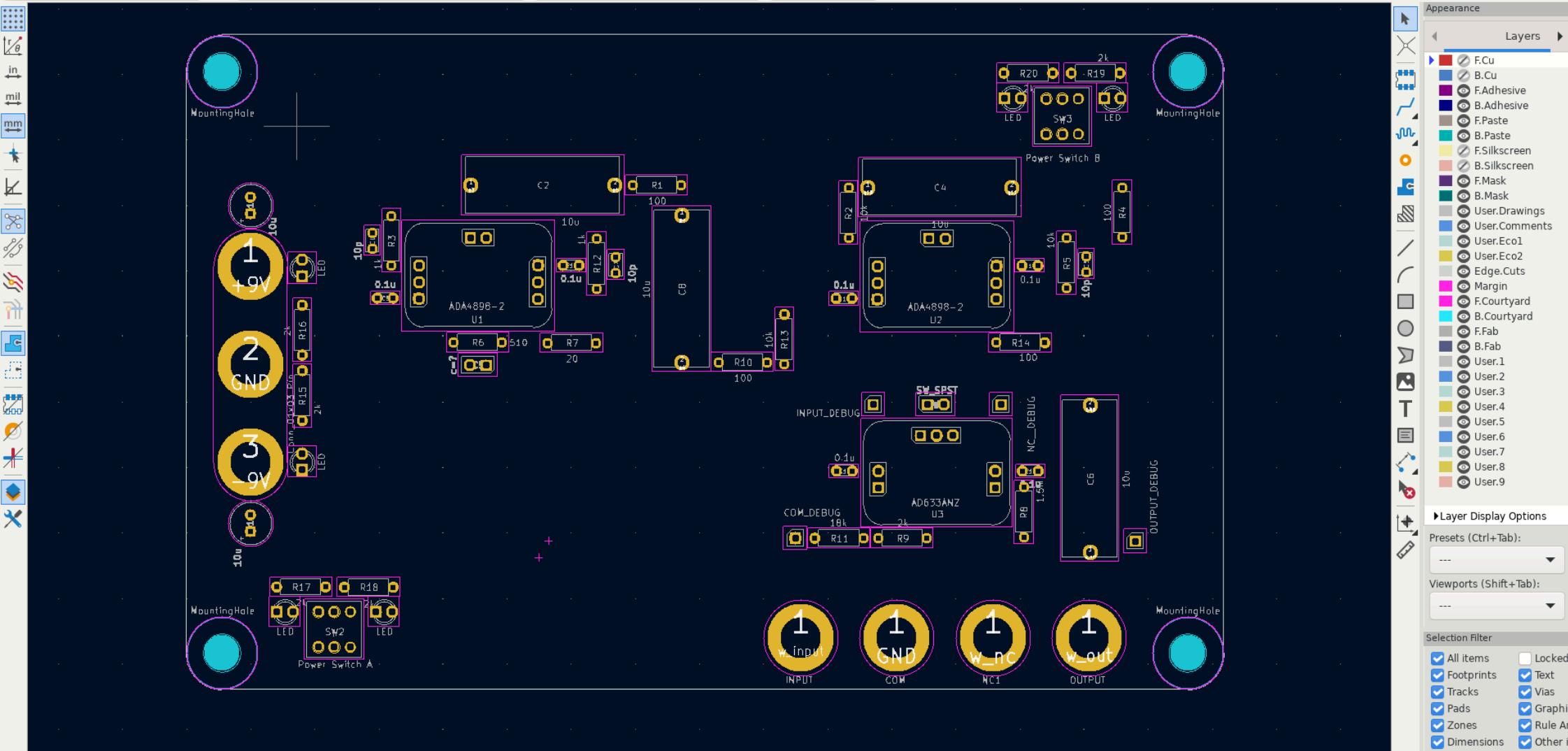


Track: use netclass width

Via: use netclass sizes

Grid: 0.0100 mm (0.0004 in)

Zoom 2.20



Pads 136
Vias 317
Track Segments 209
Nets 36
Unrouted 0

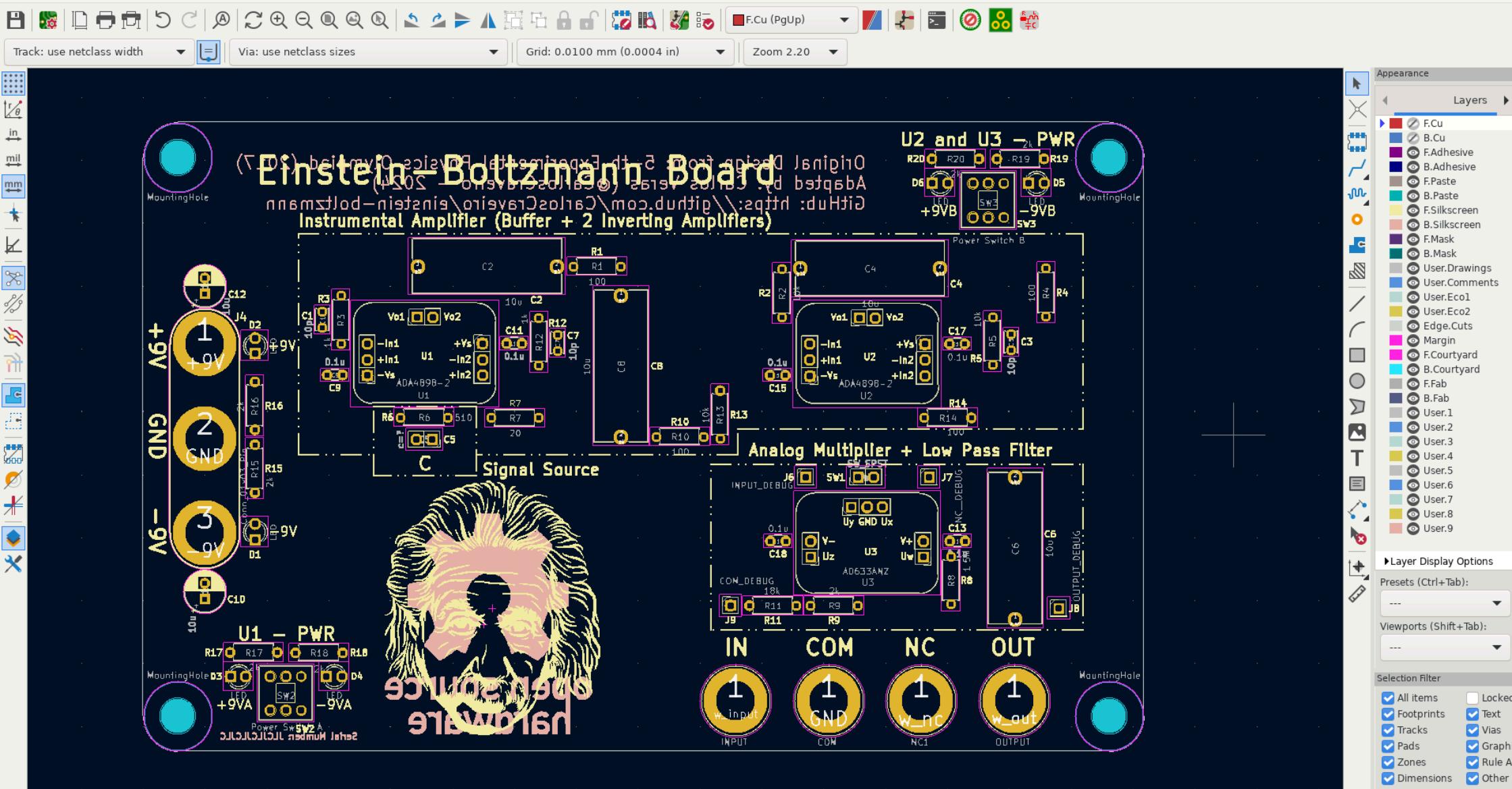
Z 2.19

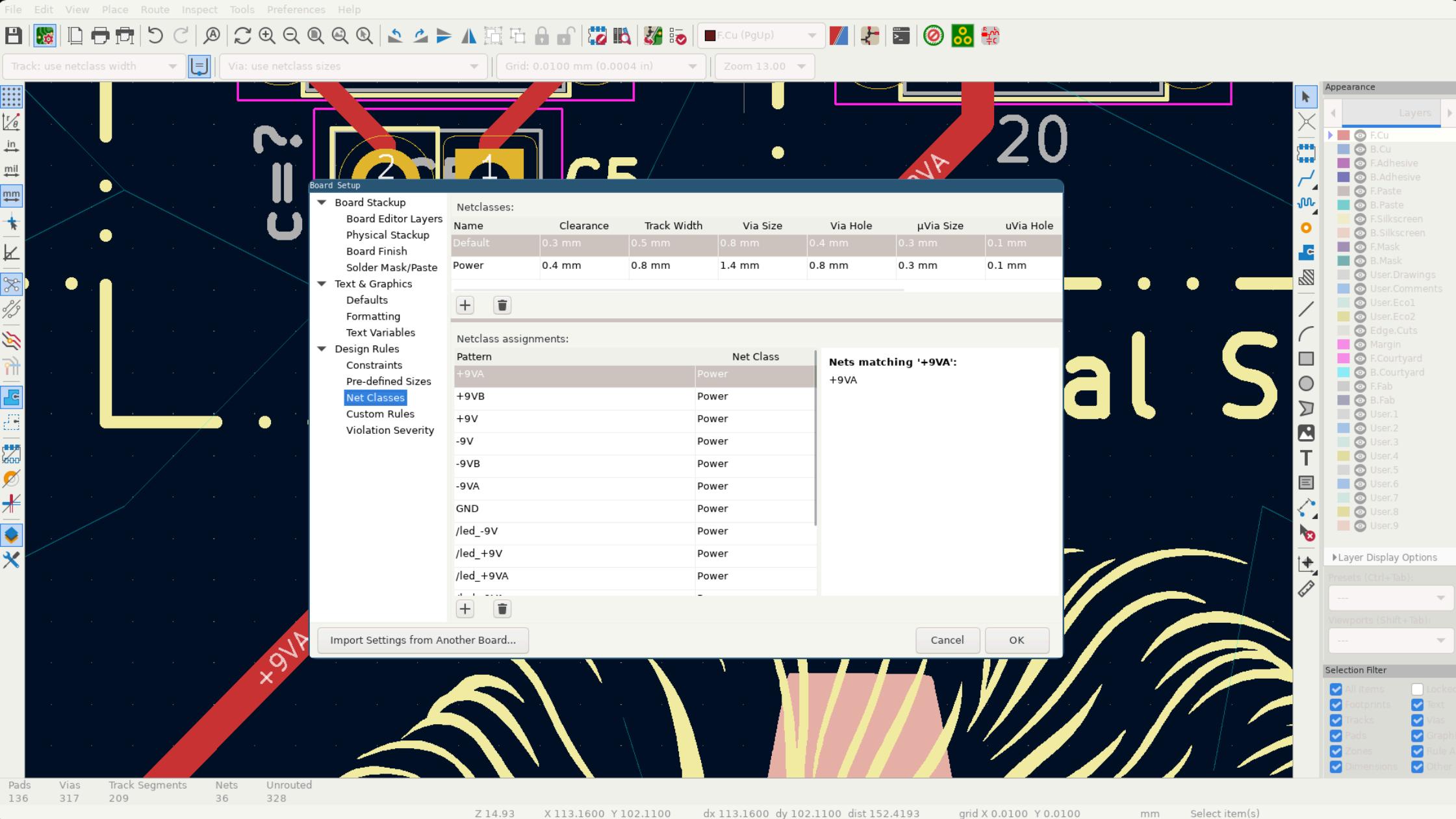
X 77.2900 Y 68.0200

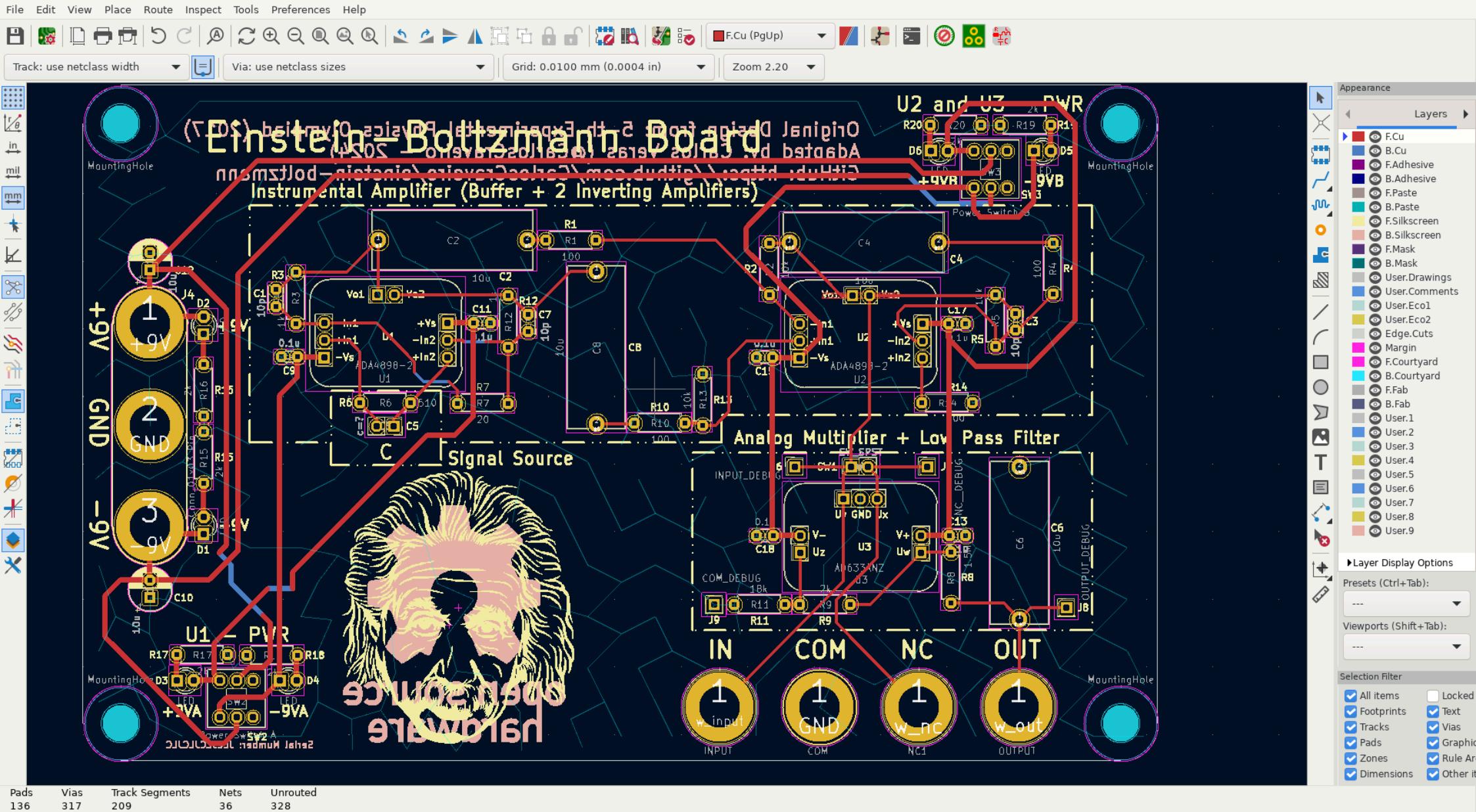
dx 77.2900 dy 68.0200 dist 102.9586

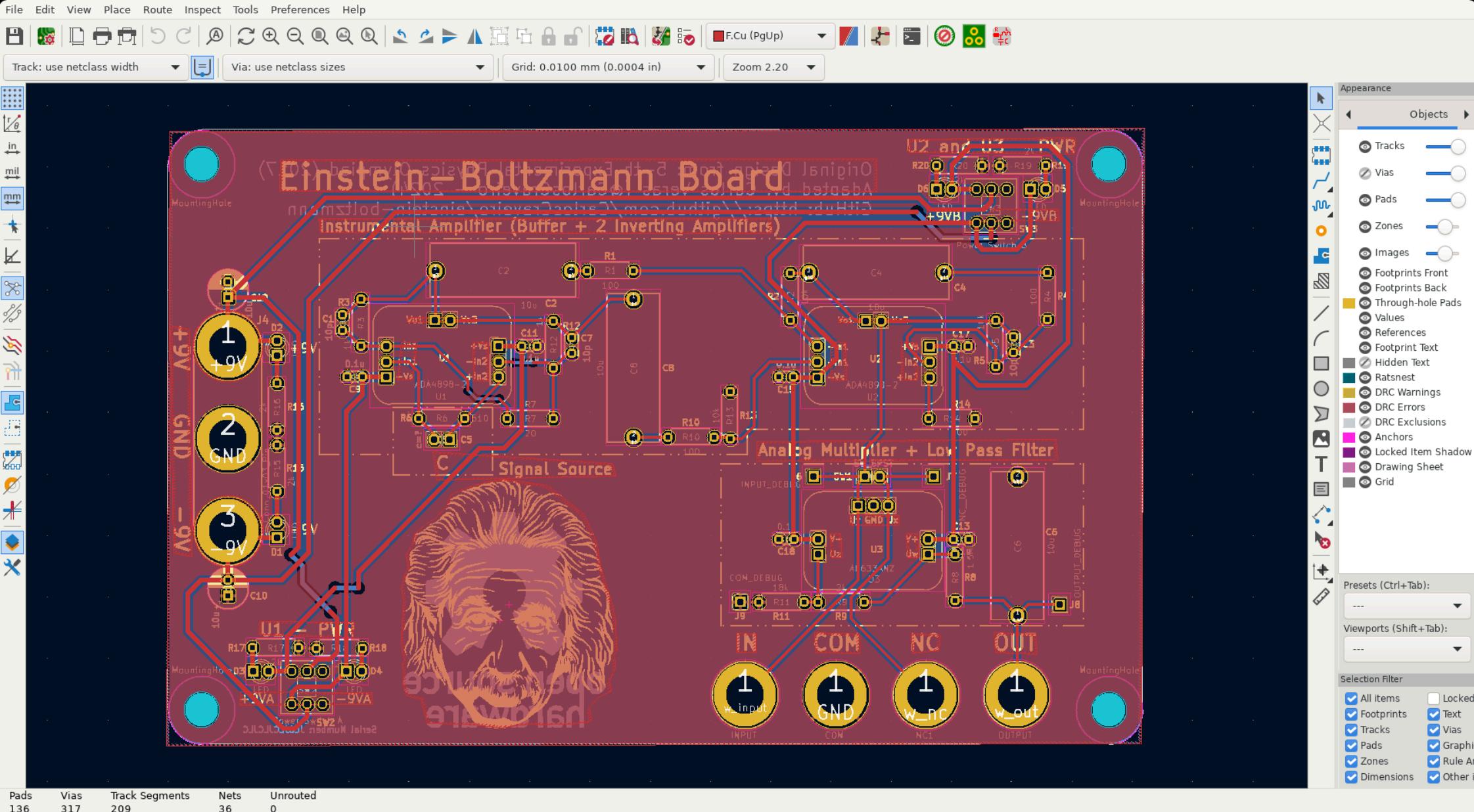
grid X 0.0100 Y 0.0100

mm









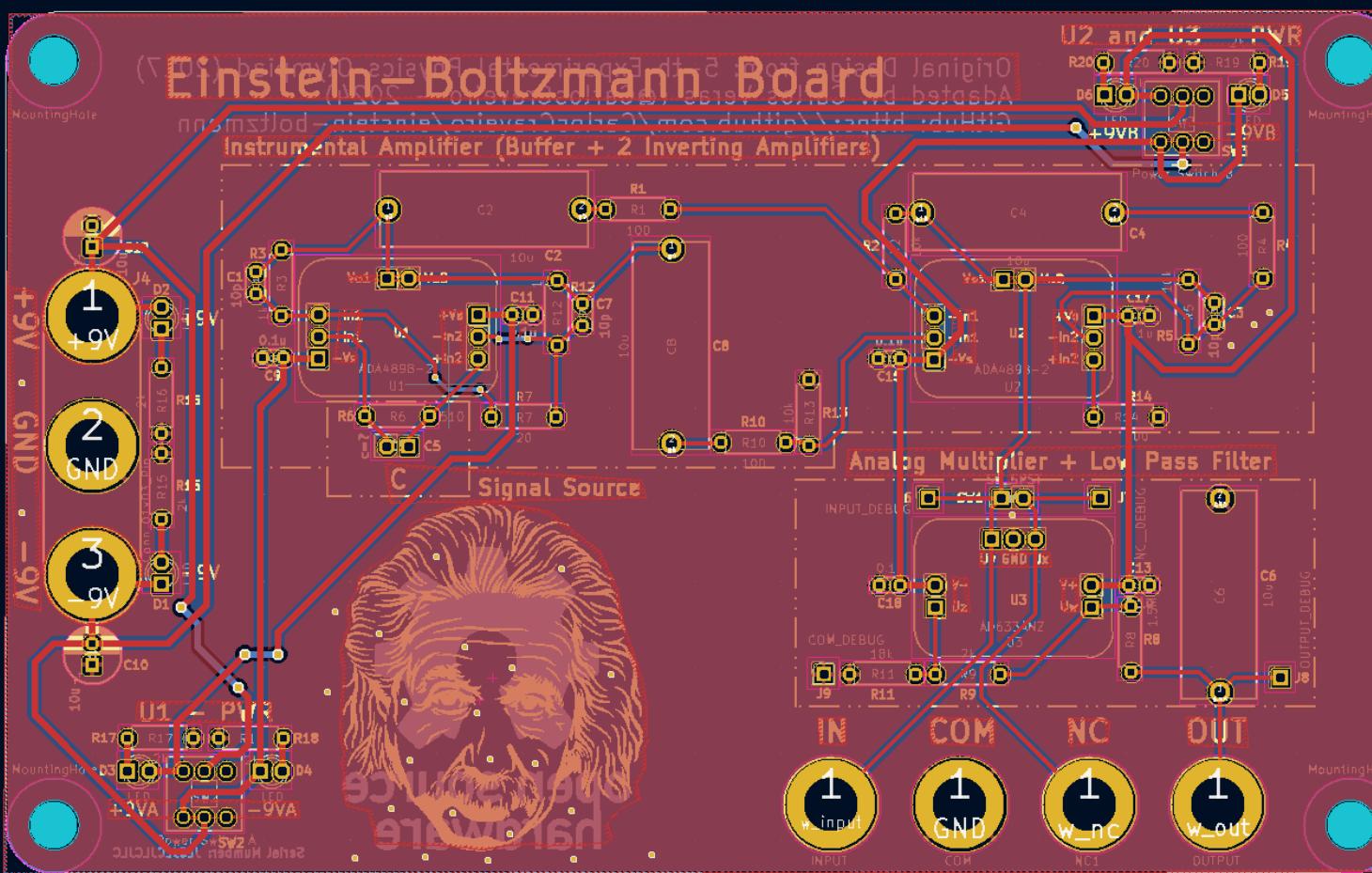


Track: use netclass width

Via: use netclass sizes

Grid: 0.0100 mm (0.0004 in)

Zoom 2.20



Pads 136
Vias 317
Track Segments 209
Nets 36
Unrouted 0

Z 2.19

X 111.5200 Y 97.2000

dx 111.5200 dy 97.2000 dist 147.9343

grid X 0.0100 Y 0.0100

mm

Select item(s)

Appearance

Layers

- F.Cu (PgUp)
- B.Cu
- F.Adhesive
- B.Adhesive
- F.Paste
- B.Paste
- F.Silkscreen
- B.Silkscreen
- F.Mask
- B.Mask
- User.Drawings
- User.Comments
- User.Eco1
- User.Eco2
- Edge.Cuts
- Margin
- F.Courtyard
- B.Courtyard
- F.Fab
- B.Fab
- User.1
- User.2
- User.3
- User.4
- User.5
- User.6
- User.7
- User.8
- User.9

Layer Display Options

Presets (Ctrl+Tab): All Layers

Viewports (Shift+Tab): ---

Selection Filter

<input checked="" type="checkbox"/> All items	<input type="checkbox"/> Locked
<input checked="" type="checkbox"/> Footprints	<input type="checkbox"/> Text
<input checked="" type="checkbox"/> Tracks	<input type="checkbox"/> Vias
<input checked="" type="checkbox"/> Pads	<input type="checkbox"/> Graphic
<input checked="" type="checkbox"/> Zones	<input type="checkbox"/> Rule Ar
<input checked="" type="checkbox"/> Dimensions	<input type="checkbox"/> Other i

KiCAD Addons

- Python plugins (Automate tasks and Add new capabilities)
- Content libraries (Shared 3rd party footprints, 3D models and symbols)
- Color themes (More customization options)

Aug 17, 19:25]

```

└[$] <git:(main)> ssh-add ~/.ssh/github
Enter passphrase for /home/coveiro/.ssh/github:
Identity added: /home/coveiro/.ssh/github (carlos.craveiro@usp.br)
[coveiro roxanne] - [~/Documents/Zedney/einstein-boltzmann] - [Sat Aug 17, 19:25]
└[$] <git:(main)> git push --force
Enumerating objects: 9, done.
Counting objects: 100% (9/9), done.
Delta compression using up to 12 threads
Compressing objects: 100% (8/8), done.
Writing objects: 100% (8/8), 3.23 MiB | 1.58 MiB/s, done.
Total 8 (delta 1), reused 0 (delta 0), pack-reused 0 (from 0)
remote: Resolving deltas: 100% (1/1), completed with 1 local object.
To github.com:CarlosCraveiro/einstein-boltzman
  + fc61df7...773ef03 main -> main (forced update)
[coveiro roxanne] - [~/Documents/Zedney/einstein-boltzmann]
└[$] <git:(main)> kicad amplifiers/amplifiers
Starting plugin CircularZone
Starting plugin ViaStitching
[coveiro roxanne] - [~/Documents/Zedney/einstein-boltzmann]
└[$] <git:(main)*> kicad tension-multiplier/tension-multiplier
Starting plugin CircularZone
Starting plugin ViaStitching
[coveiro roxanne] - [~/Documents/Zedney/einstein-boltzmann]
└[$] <git:(main)*> kicad main-board/main-board
Starting plugin CircularZone
Starting plugin ViaStitching
[coveiro roxanne] - [~/Documents/Zedney/einstein-boltzmann]
└[$] <git:(main)*> kicad main-board/main-board
Starting plugin CircularZone
Starting plugin ViaStitching
*** BUG ***
In pixman_region32_init_rect: Invalid rectangle
Set a breakpoint on '_pixman_log_error' to de
*** BUG ***
In pixman_region32_init_rect: Invalid rectangle
Set a breakpoint on '_pixman_log_error' to de
*** BUG ***
In pixman_region32_init_rect: Invalid rectangle
Set a breakpoint on '_pixman_log_error' to de
Starting plugin CircularZone
Starting plugin ViaStitching
Starting plugin CircularZone
Starting plugin ViaStitching

```

Plugin And Content Manager

The screenshot shows the KiCad Plugin And Content Manager window. At the top, there are tabs for 'Repository (81)', 'Installed (3)', and 'Pending (0)'. The 'Installed (3)' tab is selected, displaying three installed packages: 'Parasitics', 'Arcana', and 'kicad-action-scripts'. The 'kicad-action-scripts' package is highlighted with a blue border. Below the package list is a detailed view of the 'kicad-action-scripts' package, including its metadata, version history, and download options.

Version	Download Size	Install Size	Compatible	Status
7.0.4	51 kB	288 kB	✓	stable
7.0.3	51 kB	276 kB	✓	stable

Project Files

The screenshot shows the 'Project Files' interface of KiCad. It displays the contents of the 'main-board.kicad_pro' project, which includes 'main-board-backups', 'footprints.pretty', 'gerber_files', 'module_3Dmodels', 'main-board.kicad_dru', 'main-board.kicad_pcb', and 'main-board.kicad_sch' files.

Schematic Editor
Edit the project schematic

Symbol Editor
Edit global and/or project schematic symbol libraries

PCB Editor
Edit the project PCB design

Footprint Editor
Edit global and/or project PCB footprint libraries

Gerber Viewer
Preview Gerber files

Image Converter
Convert bitmap images to schematic symbols or PCB footprints

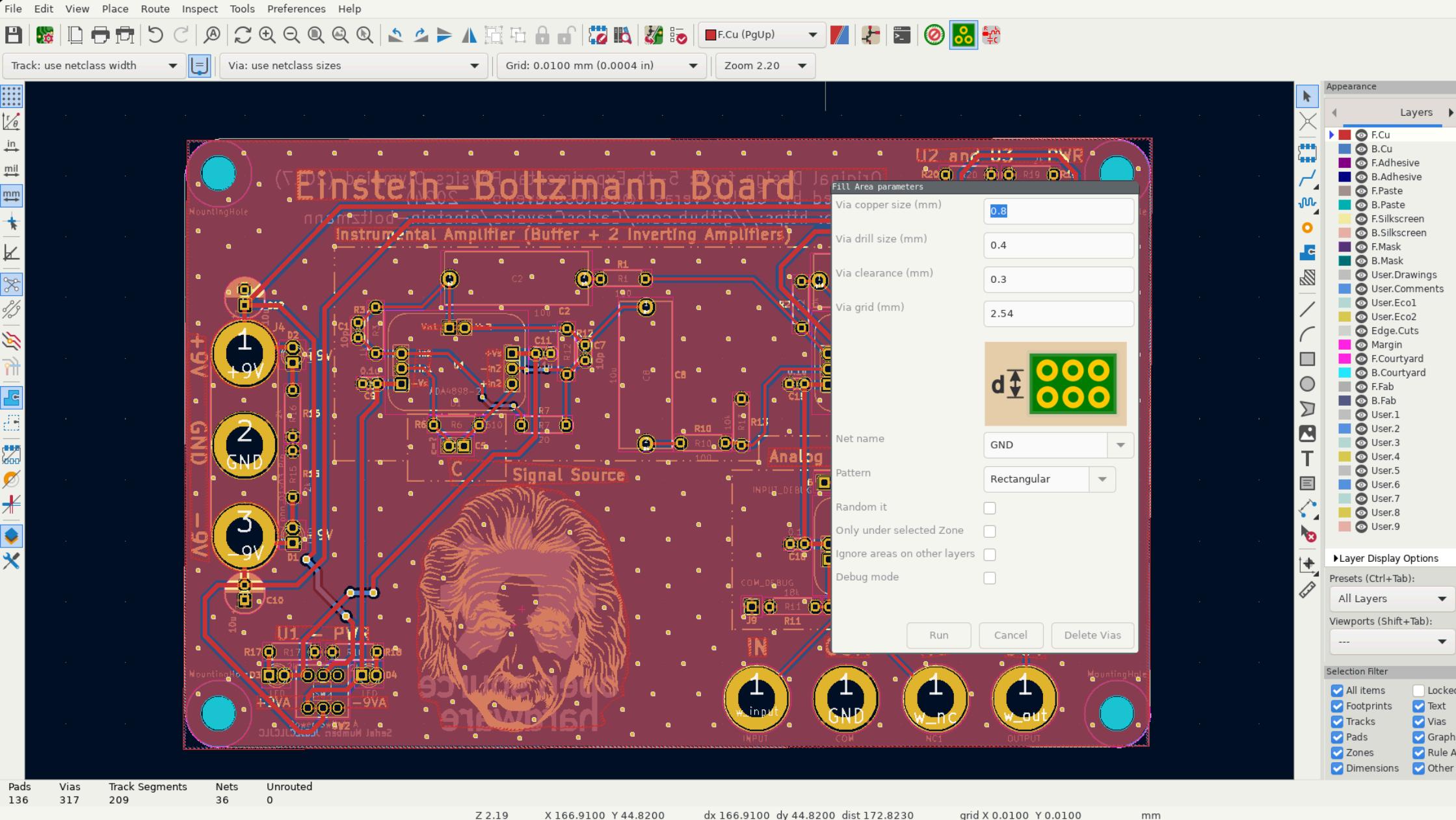
Calculator Tools
Show tools for calculating resistance, current capacity, etc.

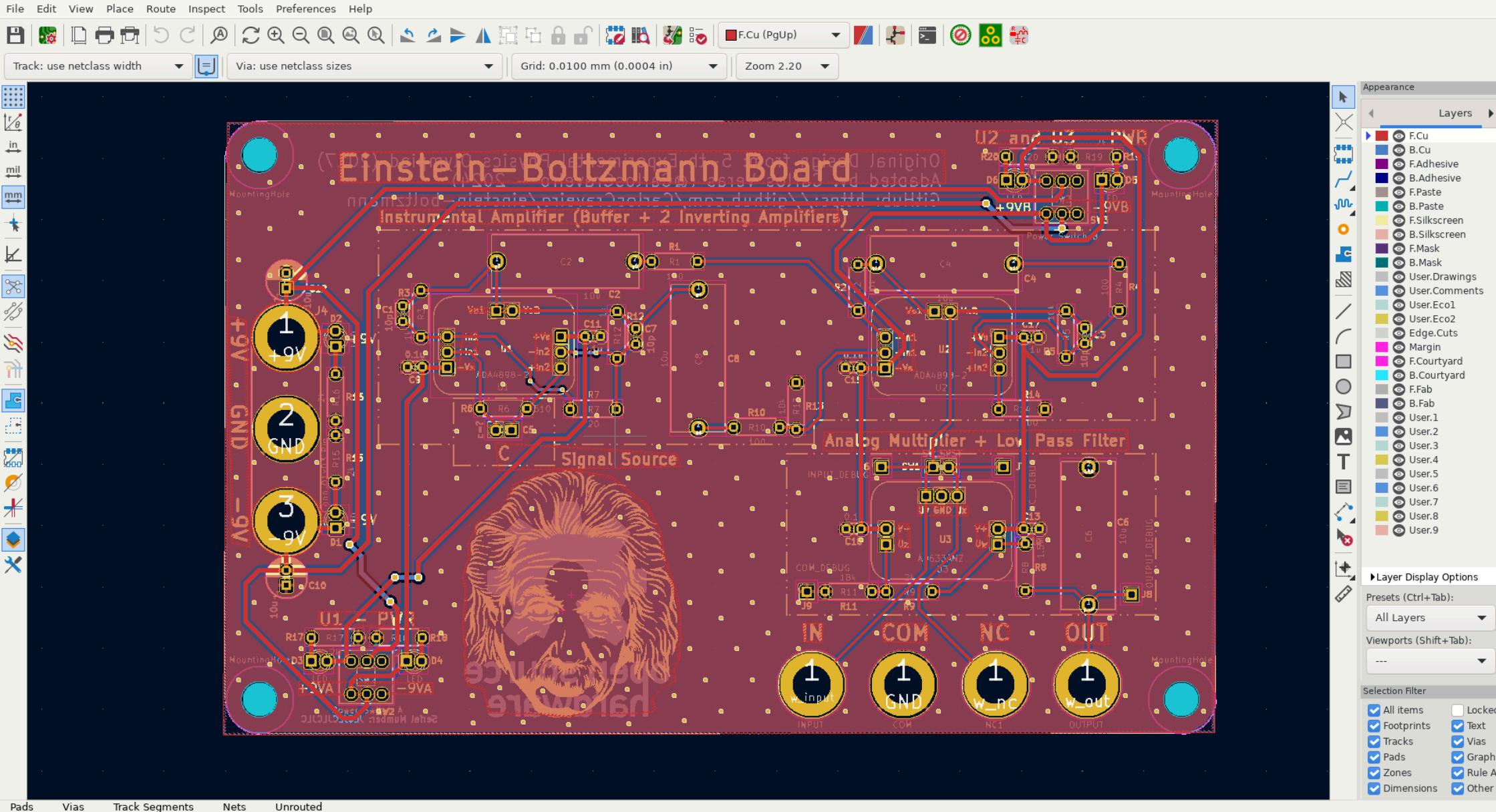
Drawing Sheet Editor
Edit drawing sheet borders and title blocks for use in schematics

Plugin and Content Manager
Manage downloadable packages from KiCad and 3rd party

File Edit View Tools Preferences Help

Project: /home/coveiro.../main-board.kicad_pro





Design Rule Checking

- Geometric constraint imposed on circuit board
- Reflects the capability of the manufacture fabrication processes
- Major step during physical verification signoff on the design
- Also involves LVS (layout versus schematic) and ERC

Design Rules Constraints UI

- Defaults
- Formatting
- Text Variables
- ▼ Design Rules
 - Constraints
 - Pre-defined Sizes
 - Net Classes
 - Custom Rules
 - Violation Severity

 Minimum connection width:	0.2	mm	Zone fill strategy
 Minimum annular width:	0.13	mm	<input type="checkbox"/> Allow fillets outside zone outline
 Minimum via diameter:	0.7	mm	 Min thermal relief spoke count: 2 - +
 Copper to hole clearance:	0.25	mm	Length tuning
 Copper to edge clearance:	0.2	mm	<input checked="" type="checkbox"/> Include stackup height in track length calculations
<hr/> Holes			
 Minimum through hole:	0.3	mm	
 Hole to hole clearance:	0.254	mm	
<hr/> uVias			
 Minimum uVia diameter:	0.2	mm	
 Minimum uVia hole:	0.1	mm	
<hr/> Silkscreen			
Minimum item clearance:	0.15	mm	



Track: use netclass width Via: use netclass sizes Grid: 0.0100 mm (0.0004 in) Zoom 1.50

Board Setup

- Board Stackup**
 - Board Editor Layers
 - Physical Stackup
 - Board Finish
 - Solder Mask/Paste
- Text & Graphics**
 - Defaults
 - Formatting
 - Text Variables
- Design Rules**
 - Constraints
 - Pre-defined Sizes
 - Net Classes
 - Custom Rules**

Violation Severity

```

DRC rules:
1 (version 1)
2 #Kicad 7
3
4 # 2-layer, 1oz copper
5 (rule "Minimum Trace Width (outer layer)"
6   (constraint track_width (min 5mil))
7   (layer outer)
8   (condition "A.Type == 'track'")
9
10 (rule "Minimum Trace Spacing (outer layer)"
11   (constraint clearance (min 5mil))
12   (layer outer)
13   (condition "A.Type == 'track' && B.Type == A.Type"))
14
15 # 4-layer
16 (rule "Minimum Trace Width and Spacing (inner layer)"
17   (constraint track_width (min 3.5mil))
18   (layer inner)
19   (condition "A.Type == 'track'")
20
21 (rule "Minimum Trace Spacing (inner layer)"
22   (constraint clearance (min 3.5mil))
23   (layer inner))

```

No errors found.

Import Settings from Another Board... Cancel OK

Appearance

Layers

F.Cu
B.Cu
F.Adhesive
B.Adhesive
F.Paste
B.Paste
F.Silkscreen
B.Silkscreen
F.Mask
B.Mask
User.Drawings
User.Comments
User.Eco1
User.Eco2
Edge.Cuts
Margin
F.Courtyard
B.Courtyard
F.Fab
B.Fab
User.1
User.2
User.3
User.4
User.5
User.6
User.7
User.8
User.9

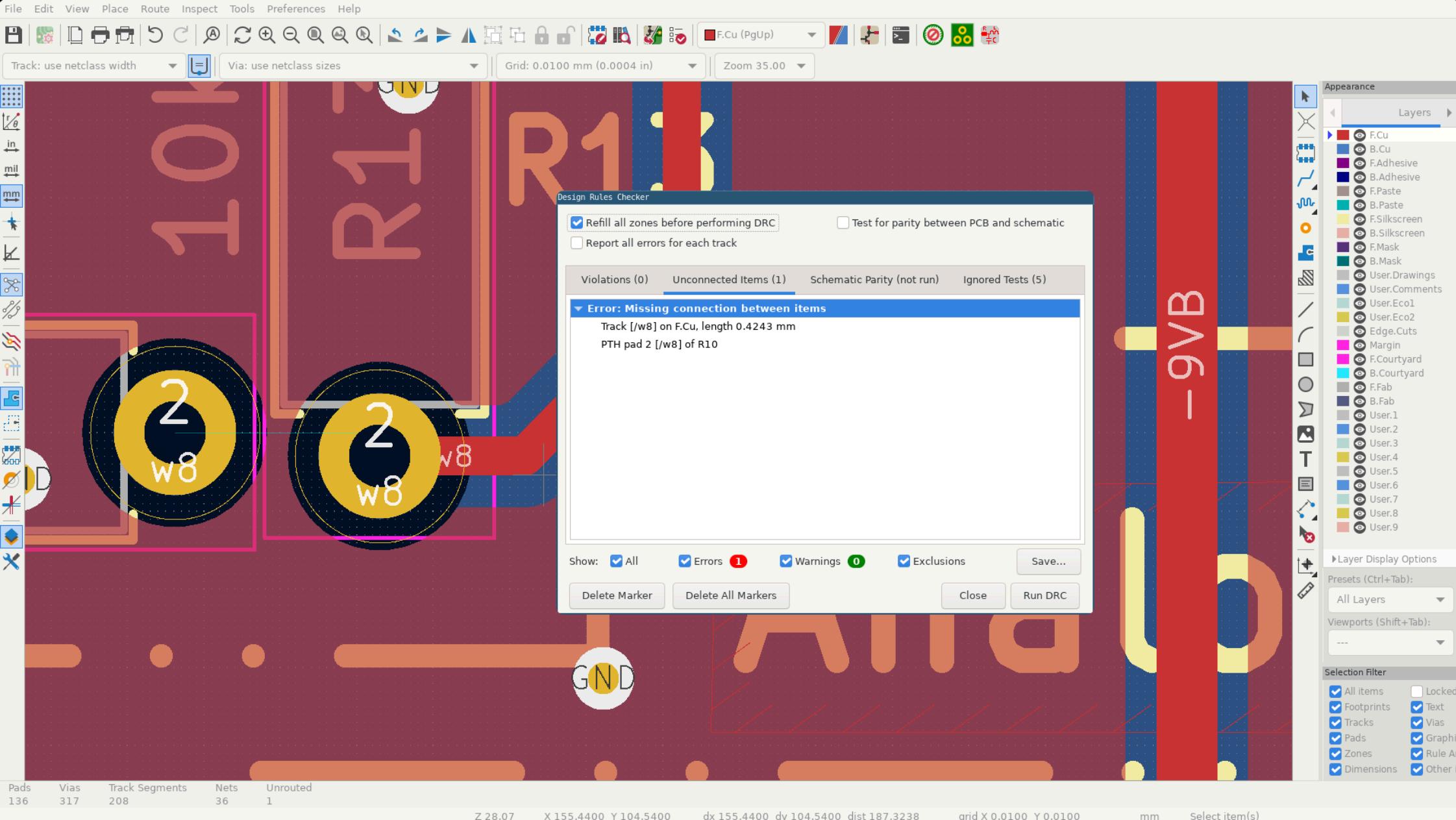
Layer Display Options

Presets (Ctrl+Tab): All Layers

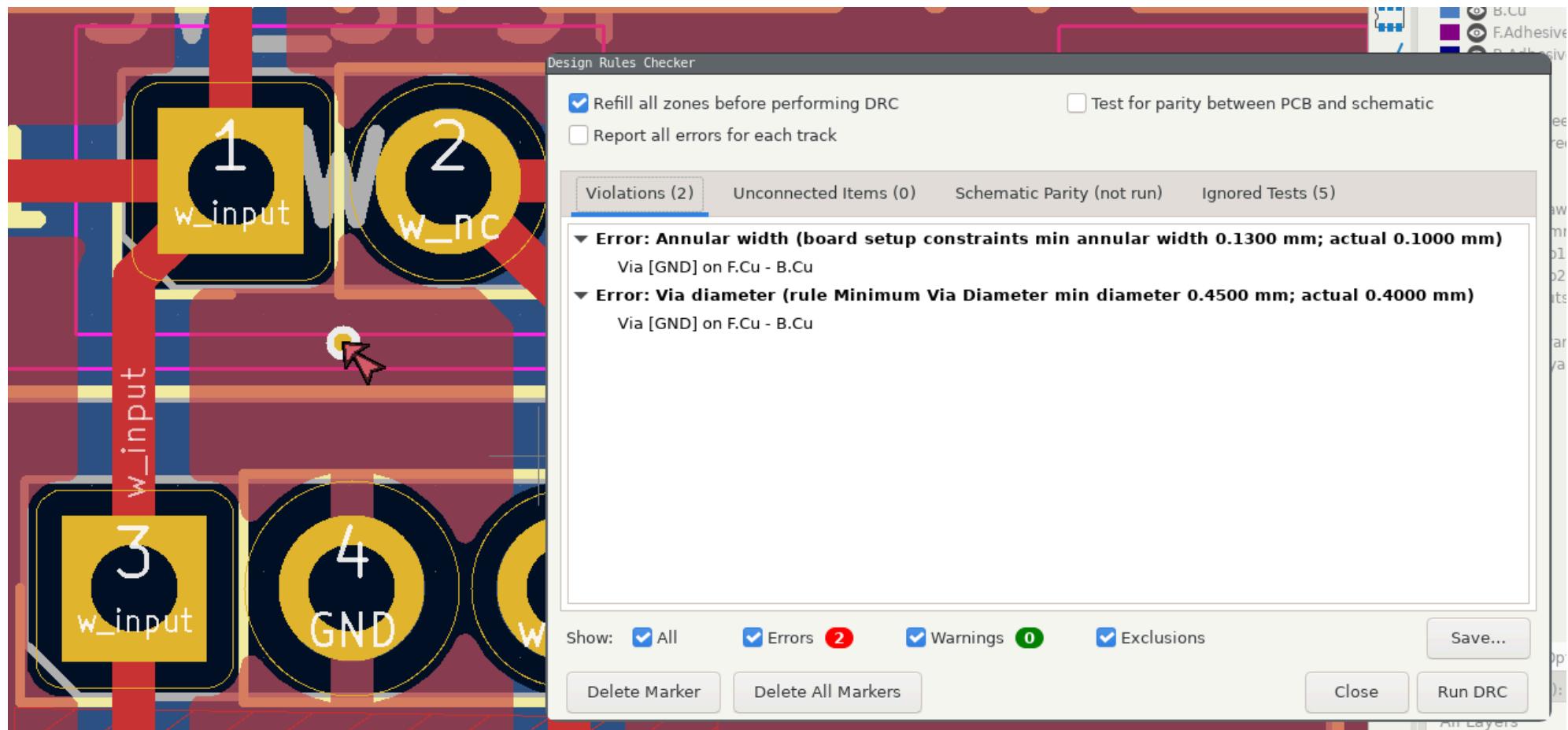
Viewports (Shift+Tab): ---

Selection Filter

<input checked="" type="checkbox"/> All items	<input type="checkbox"/> Locked
<input checked="" type="checkbox"/> Footprints	<input type="checkbox"/> Text
<input checked="" type="checkbox"/> Tracks	<input type="checkbox"/> Vias
<input checked="" type="checkbox"/> Pads	<input type="checkbox"/> Graphic
<input checked="" type="checkbox"/> Zones	<input type="checkbox"/> Rule Ar
<input checked="" type="checkbox"/> Dimensions	<input type="checkbox"/> Other it

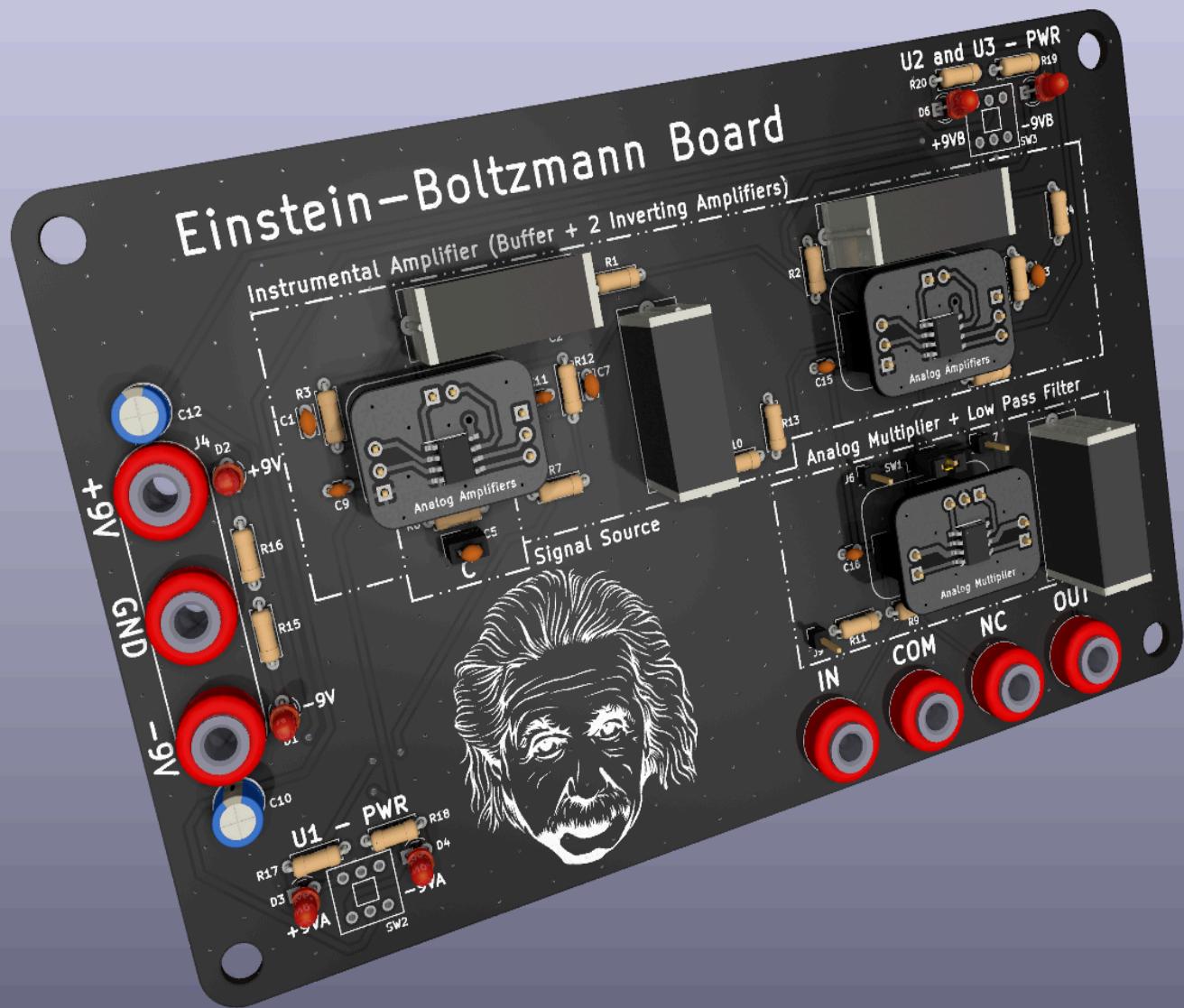


Constraint Violation



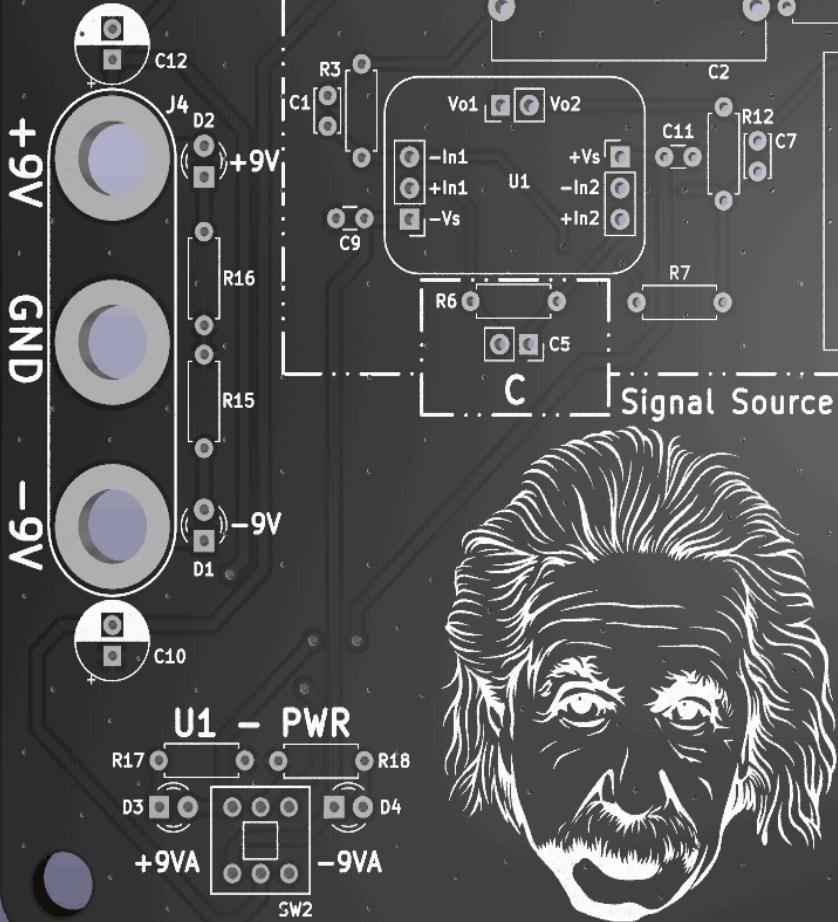
3D Visualization

- OpenGL (GPU accelerated), and ray tracing
- Helps to verify the Design by visual inspection
- Get an idea about how the project may look like when it is finished

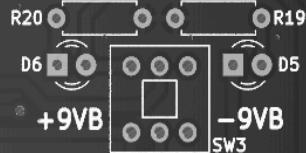


Einstein-Boltzmann Board

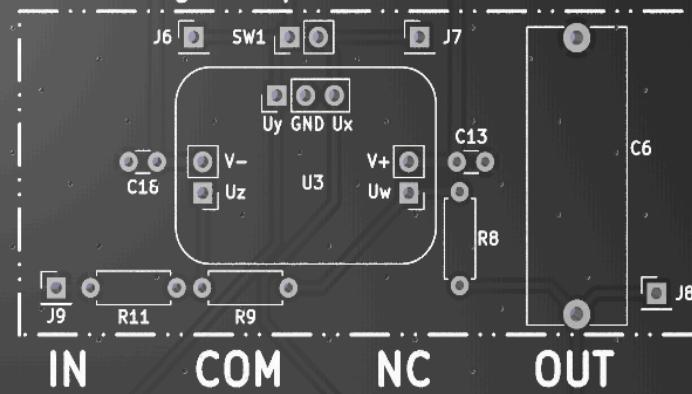
Instrumental Amplifier (Buffer + 2 Inverting Amplifiers)



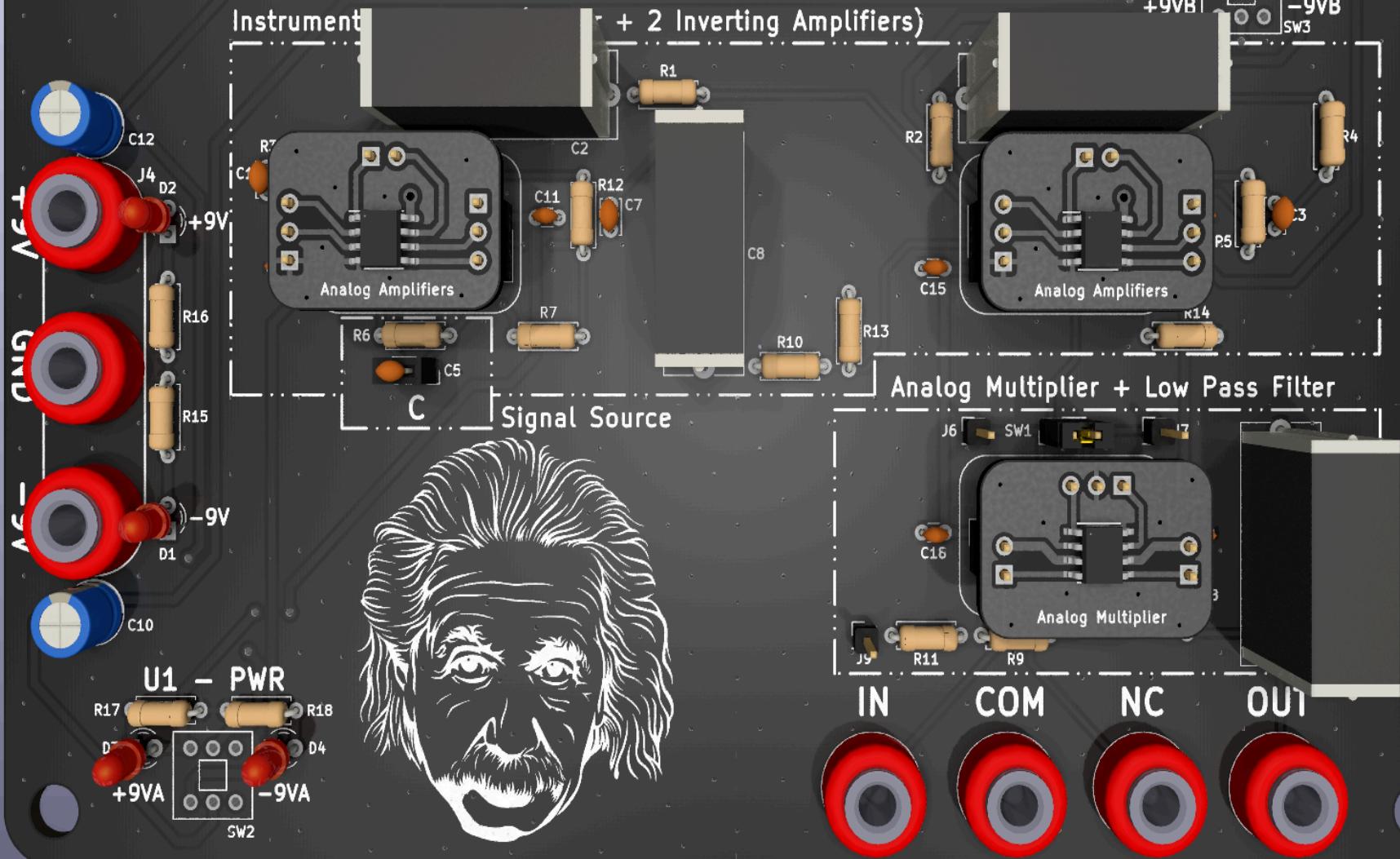
U2 and U3 - PWR

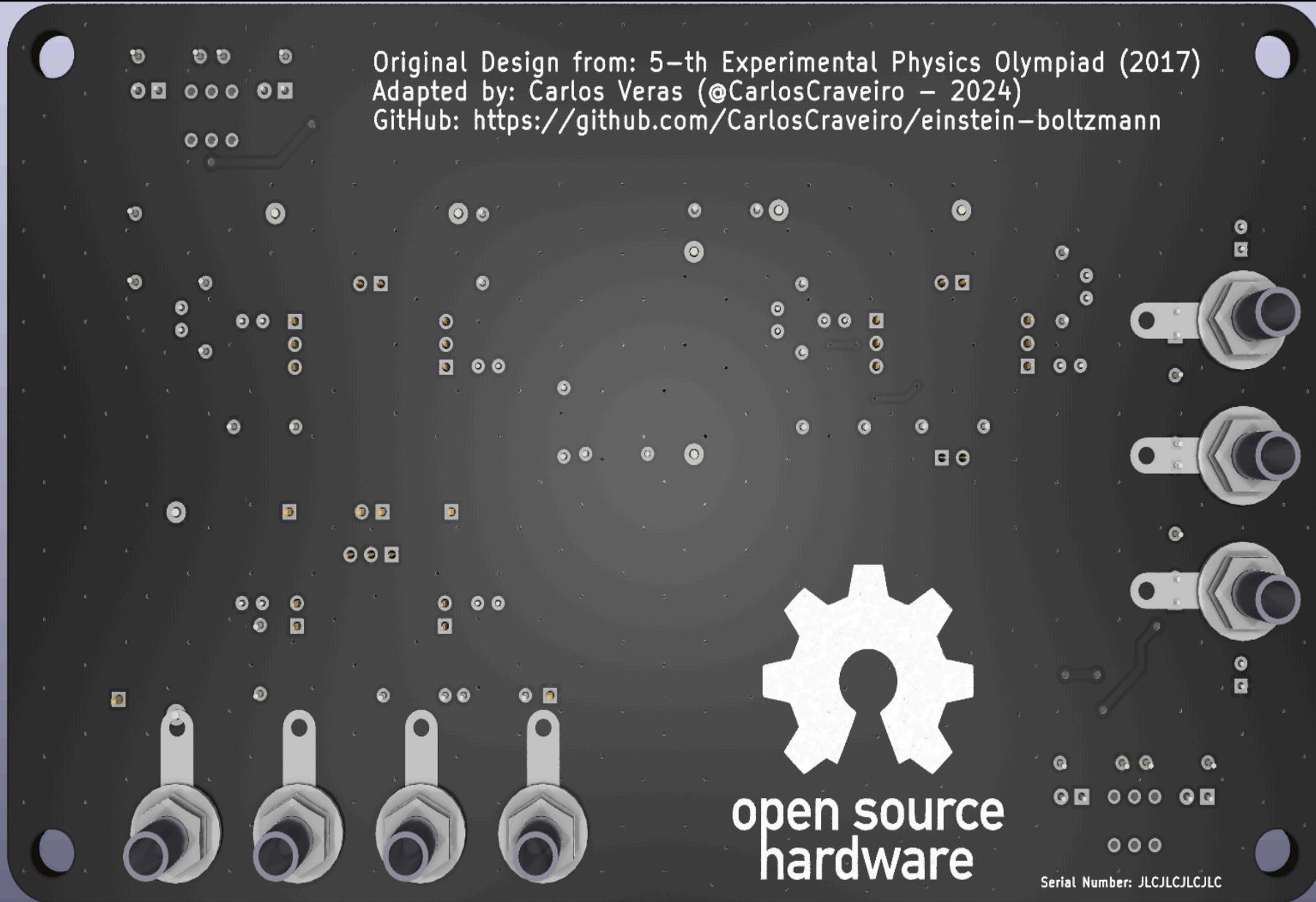


Analog Multiplier + Low Pass Filter



Einstein-Boltzmann Board





Original Design from: 5-th Experimental Physics Olympiad (2017)
Adapted by: Carlos Veras (@CarlosCraveiro – 2024)
GitHub: <https://github.com/CarlosCraveiro/einstein-boltzmann>

Serial Number: JLCJLCJLCJLC

Issues I faced

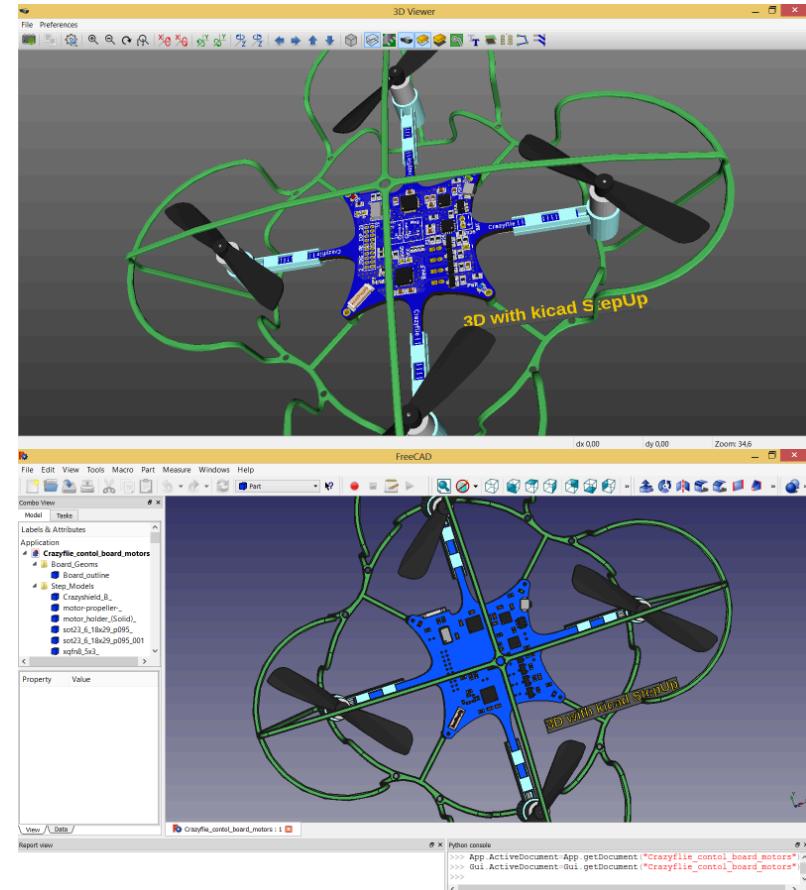
- Multi-project with KiCAD is terrible
- The simulation tool was poorly documented (KiCAD 7)
- I couldn't simulate my circuit as I wanted
- Customization is a bit too laborious (issues with shortcuts)

Future Work

- Check if the board actually works
- Determine the Boltzmann Constant (Have fun with the project!)
- Reduce costs: find cheaper OPamps, decrease PCB size, ...
- Check for design flaws and possible improvements

Future Work

- Setup a KicadStepUp Workbench at FreeCAD
- Make the simulation work
- Improve project's documentation



References

- 1 - Mishonov, T. M., Petkov, E. G., Stefanov, A. A., & Petkov, A. P. (2018). **Measurement of the Boltzmann constant by Einstein: Problem of the 5th Experimental Physics Olympiad** (Sofia, 9 December 2017). Retrieved from <https://arxiv.org/pdf/1801.00022v3>
- 2 - Lathi, B. P., Ding, Z. (2009). Modern Digital and Analog Communication Systems. United Kingdom: Oxford University Press.

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