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Advanced Instrumentation Lectures: PCB Design with KiCad

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Oxford Physics Microstructure Detector
Laboratory

Outline



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Session 1 (Tuesday)

- **Recap on PCB basics (see Sneha's lecture)**
- **Intro to KiCad**
- **Comparison of KiCad to other programs**
- **Quirks / drawbacks to be aware of in KiCad**
- **KiCad workflow options – symbols, footprints etc**
- **Component suppliers & BOM considerations**
 - **RS, Farnell, Mouser, Digikey**
 - **Octopart**
- **PCB Manufacturing Houses**
 - **Newbury/PCBTrain (UK)**
 - **The “boutique” shops (UK)**
 - **China: example Seedstudio Fusion**
- **KiCad install & Schematic Editor demo**

Session 2 (Friday)

- **KiCad Schematic Editor demo (continued, with SPICE)**
- **KiCad PCB Editor demo (routing, netclasses)**
- **Exporting for Manufacture (gerbers, BOM)**
- **Exporting for mechanical CAD**

PCB Basics recap



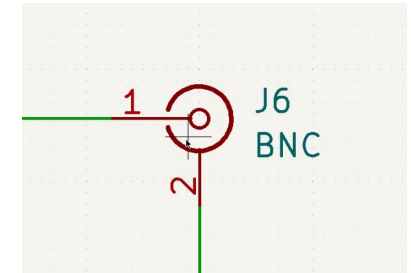
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Talk by Sneha Naik earlier in this series:

<https://indico.cern.ch/event/1129266/contributions/4821483/>

Make sure you know the basics of the following words (ask if any are unclear):

Schematic, Board artwork, Symbol, Footprint, Layer, ERC, DRC, BOM



Copper

- Minimum clearance: 0 mm
- Minimum track width: 0.125 mm
- Minimum annular width: 0.05 mm
- Minimum via diameter: 0.4 mm
- Copper to hole clearance: 0.25 mm
- Copper to edge clearance: 0.025 mm

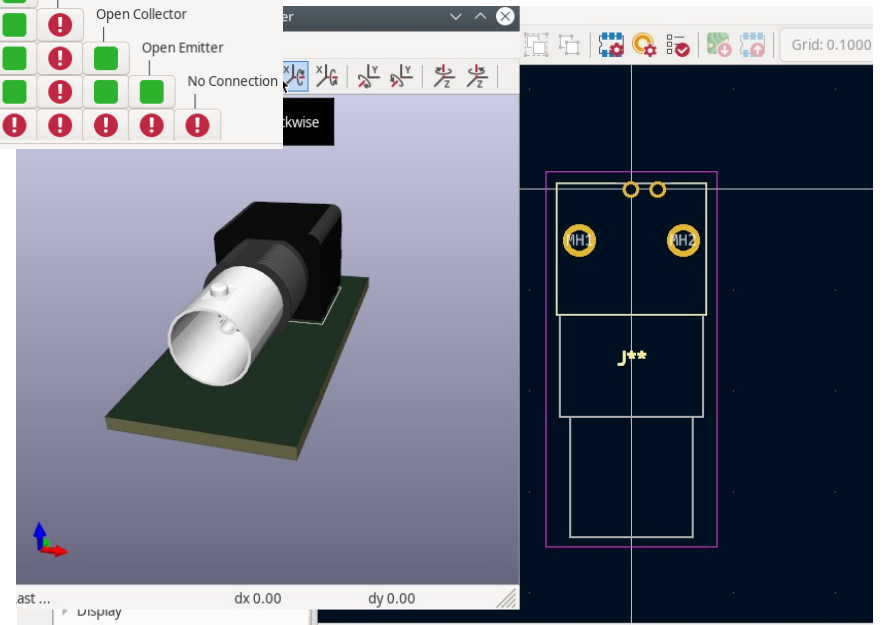
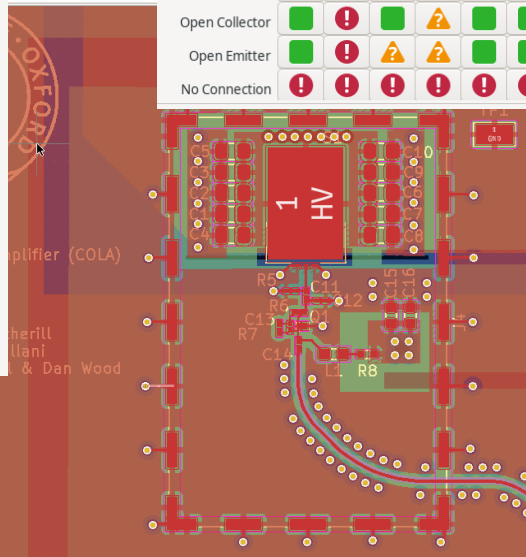
Holes

- Minimum through hole: 0.3 mm
- Hole to hole clearance: 0.25 mm

uVias

- Minimum uVia diameter: 0.2 mm

Input Pin	Output Pin	Bidirectional Pin	Tri-State Pin	Passive Pin	Free Pin	Unspecified Pin	Power Input Pin	Power Output Pin	Open Collector	Open Emitter	No Connection



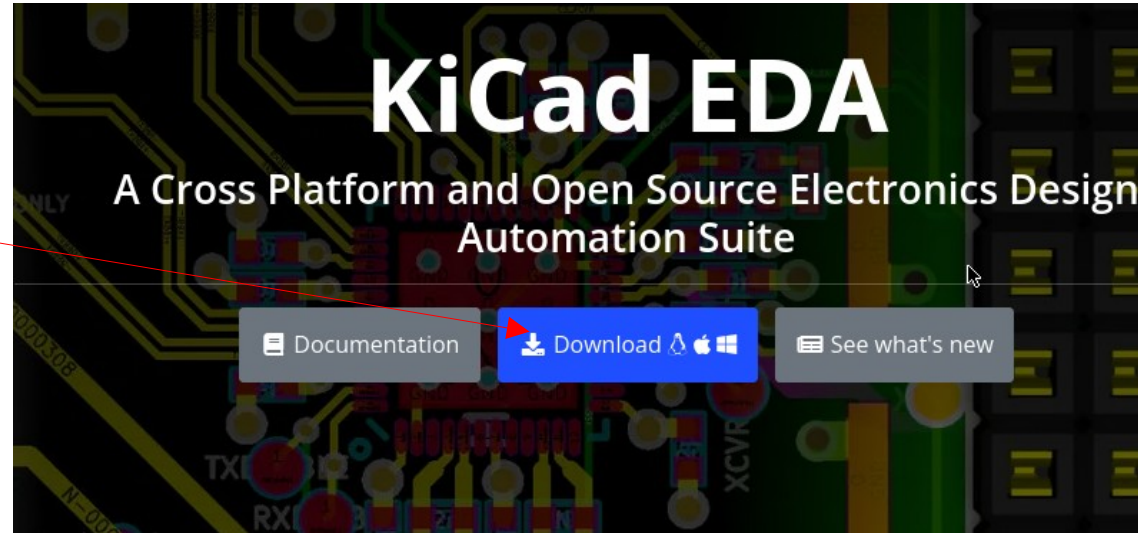
Intro to KiCad

Get kiCAD here (we're using version 6)

<https://www.kicad.org/>

Good place to get help on KiCAD usage:

<https://forum.kicad.info/>



KiCad (pronounced “key-CAD” by original authors) began development in 1992 (!!) by Jean-Pierre Charras. Since ~2015 managed by Wayne Stambaugh + a team of developers (including at CERN). It is open source and you can contribute fixes & code.

Probably the best known, supported and widely used free, open source PCB design software.

Please try and download and install now if you Haven't already

CERN contribution:

<https://ohwr.org/project/cern-kicad/wikis/home>



Other Programs vs KiCad



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Very popular, free version available. Similar in features to KiCad (more advanced in some ways). Widely supported

See also: diptrace, designspark

But: every new version since Autodesk takeover gets more “locked down”. Free version limited in layer count & board size. Kicad can (quite well) import Eagle projects

Much more advanced “professional level” features that Kicad lacks (controlled impedance, stackup management, integrated parts database etc etc). Very good interface but with some learning curve.

Recommend starting with a simpler tool (like KiCad) to design some simple boards and perhaps pick up something like Altium later. Kicad can import Altium projects though it is still quite an experimental feature



See also: OrCAD / Cadence Allegro, Mentor Graphics (PADS)

Interoperability



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From mechanical CAD, you may be familiar with STEP / IGES, which allow (reasonable) interchange of designs between programs & for manufacturers. You need to be (vaguely) aware of some of this as it may affect exchanging designs with colleagues & fabrication houses.

For PCB design, the story is not quite as good. There is no good “schematic + PCB” export but there are some options:

- **Gerber “RS-274X/X2”** – the standard format that you will send to most board houses. Exports PCB artwork so it can be manufactured, but doesn’t really know anything about the circuit connectivity (no schematic information).
- **ODB++** - many “pro” level CAD programs support this and can exchange designs between them. **KiCad does not (yet) support it**, it is planned for version 7
- **IPC-2511b “GenCAD/GenCAM”** – similar format to ODB++ but less widely adopted, though it is an open standard. **KiCad can export an old version of GenCAD**, but it is not very widely used. **If you use GenCAD export in KiCad you should check the output it generates carefully with an external tool! (for example <https://www.circuitcam.com/download>)**
- **IPC-2581** – “next generation” export format, which (may) eventually replace Gerber. Planned for KiCad to support it, **but it doesn’t yet! This is a problem for some (very few!) manufacturers, who now demand IPC-2581 rather than Gerber (see later)**
- **IPC-D-356A** – this is a netlist (rather than PCB artwork) format. Some board houses that do electrical test want it, KiCad **can export this**
- **Gerber “X3”** – the latest Gerber spec includes information similar to IPC-2581. KiCad **fully supports Gerber X3** . Sadly, most other programs do not, as it has not gained as much popularity as IPC-2581.
- Some board fabrication houses (e.g. in China) now accept KiCad project files directly! However, most of them don’t yet accept version 6.0 (only version 5.0), so ideally **steer clear of this!**

Things to beware of in KiCad



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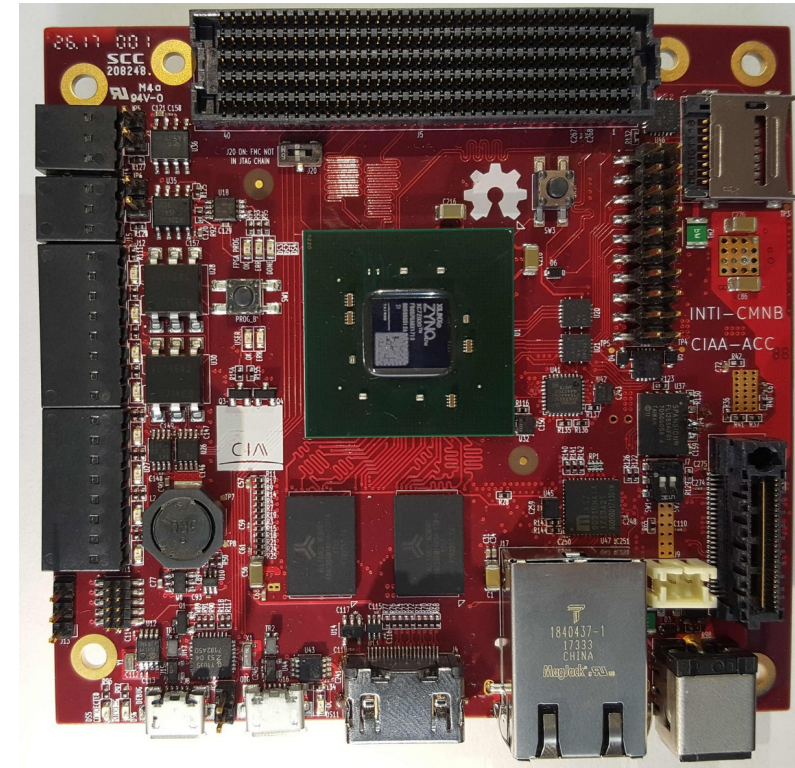
- **Not much physical layer stackup Awareness**
Actually, KiCad 6 does have layer stackup now! And it can be included in basic constraints. BUT, not very good support yet for automatic controlled impedance traces (they can be done manually with some effort though!)
- **Have to choose a library workflow**
Disagreements in community about whether to use “atomic” or “default” type parts (see later). Have to be careful with either choice (can mix & match to some extent)
- **Lack of IPC-2581 export**
Some board houses want this now. It isn't there yet in KiCad
- **Backward/Forward Compatibility Issues**
Old versions of KiCad cannot open newer file versions. But new versions can import and migrate old projects very well
- **Some functionality needs plug-ins**
Many of the really useful and advanced stuff is in community plugins. Over time more has moved into core (e.g. curved traces are now built in, but things like RF via stitching are still done through a plugin)
- **Included “standard” libraries are often not very good**
The built in standard part library only includes a weird and narrow selection and KiCad is not as good as Eagle or Altium when it comes to getting new parts. They have to be manually downloaded, rather than a nice “Wizard” dialog that you get in Altium
- **Grid system in Schematic entry is errr....**
Well actually it's much better in 6.x than 5.x, but still annoying at times

...And the Good News!



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- **Huge community of users** – lots of people on the forums, IRC, around and about use this software
 - **Open Source, no limits on “free” version** – no limits on board size, layers etc etc
 - **Usable on “real” designs and in industry** – though it is a bit more limited than e.g. Altium, make no mistake KiCad is a professional grade tool
 - **Text based file formats** – compatible with git version control! (And visual diff tools available, so merging is possible!)
 - **Scriptable** – you can write plugins and processing tools in the python language to do custom features in KiCad.
 - **pretty good (manual) routing experience**- advanced push’n’shove and other modern routing techniques are very well implemented and very usable. Better IMO than Eagle or Diptrace
 - **No built-in autorouter** – autorouters almost ALWAYS get everything wrong anyway. An external autorouter (FreeRouting) is available if you really want it
- (right)** – CIAA-ACC 12 layer board with Xilinx 7000 Series SOC and kintex-7 FPGA. Running at GHz speed, A “very serious” design” done in KiCad!



KiCad Part workflow options



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Kicad has no “built in” concept of a **part** (i.e. **footprint + symbol**). You can associate any schematic symbol with any footprint! This can be useful for quick designs and parts available in alternate footprints but **it is easy to make very bad errors which ERC will not save you from!**

Many serious people refuse to use KiCad for this exact reason (same applies to Eagle and, especially, DipTrace). Personally I don't mind it but have fallen prey to a pinout error a couple of times over the years!

Luckily, if you want to use **atomic parts**, KiCad can support this! Tools such as componentsearchengine (see later) let you download parts in kind of atomic format

Atomic parts

Every different part (including different footprints of the same part), has a separate symbol & footprint in your KiCad library. Each symbol is associated to one (and ONLY one) footprint.

Pro: it's very hard to make a very silly pinout mismatch error

Con: maintaining this parts library is a HUGE amount of work

KiCad default

Each symbol in the schematic must be manually associated with a footprint when you design the board (but usually they have a default)

Pro: much quicker to get up and running, easier and more flexible to alter designs later
Con: you MUST DOUBLE CHECK FOOTPRINT ASSOCIATION VERY VERY CAREFULLY

Buying Components - UK



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Sorting out the BOM is (usually) actually the most tedious part of a PCB Design project!

My personal recommendation – start with Farnell! (<https://uk.farnell.com/>)
Good search interface, wide selection, reasonable price.

The screenshot shows the Farnell website search results for the part number 'tl081'. The search bar at the top contains 'tl081' and a search icon. Below the search bar, there are navigation links for 'All Products', 'Manufacturers', 'Resources', and 'Communities'. The search results are displayed in a table with columns for Manufacturer Part No, Order Code, Description / Manufacturer, Availability, Price For, Price (ex VAT), Quantity, No. of Amplifiers, Bandwidth, Slew Rate, Supply Voltage Range, Amplifier Case Style, and No. of Pins. Three results are shown: TL081ID (Operational Amplifier, 1 Amplifier, 3 MHz, 13 V/us, 7V to 36V, SOIC, 8 Pins), TL081CP (Operational Amplifier, 1 Amplifier, 4 MHz, 13 V/us, 7V to 36V, DIP, 8 Pins), and TL081CD (Operational Amplifier, Single, 1 Amplifier, 3 MHz, 13 V/us, 7V to 36V, SOIC, 8 Pins). The TL081ID and TL081CP parts are in stock, while the TL081CD part is available for back order.

Manufacturer Part No	Order Code	Description / Manufacturer	Availability	Price For	Price (ex VAT)	Quantity	No. of Amplifiers	Bandwidth	Slew Rate	Supply Voltage Range	Amplifier Case Style	No. of Pins
TL081ID	3005131	Operational Amplifier, 1 Amplifier, 3 MHz, 13 V/us, 7V to 36V, SOIC, 8 Pins TEXAS INSTRUMENTS	In stock	Each	1+ £1.08 10+ £0.933 50+ £0.757 100+ £0.733 250+ £0.708	1	1 Amplifier	3MHz	13V/us	7V to 36V	SOIC	8Pins
TL081CP	3117808	Operational Amplifier, 1 Amplifier, 4 MHz, 13 V/us, 7V to 36V, DIP, 8 Pins TEXAS INSTRUMENTS	Available for back order. More stock available week commencing 29/05/23	Each	1+ £0.563 10+ £0.496 100+ £0.352 500+ £0.299 1000+ £0.24	1	1 Amplifier	4MHz	13V/us	7V to 36V	DIP	8Pins
TL081CD	3117806	Operational Amplifier, Single, 1 Amplifier, 3 MHz, 13 V/us, 7V to 36V, SOIC, 8 Pins TEXAS INSTRUMENTS	Available for back order. More stock available week commencing 29/05/23	Each	1+ £1.45	1	1 Amplifier	3MHz	13V/us	7V to 36V	SOIC	8Pins

If a part is not on Farnell, it is likely on Mouser (www.mouser.co.uk) or digikey (www.digikey.co.uk). In some circumstances, it might be on RS (<https://uk.rs-online.com/web/>)

STRONG RECOMMENDATION: include both MPN (“manufacturer part number”) and the order code for a particular supplier in your schematic. Then, stock issues can be more easily sorted out via OctoPart or by the board assembly house

Octopart



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Always put a manufacturer part number (MPN) in your schematic data!
You can use the tool www.octopart.com to find this part on many different suppliers, and sometimes to obtain CAD data downloads.

The screenshot shows the KiCad PCB Editor interface. The main window displays a schematic diagram of an OPA858 op-amp circuit. The op-amp is labeled U15. It is configured as a voltage follower. The non-inverting input (pin 4) is connected to a 10k resistor (R72) and a 100nF capacitor (C56) to ground. The inverting input (pin 7) is connected to the output (pin 1). The output (pin 1) is also connected to a 100nF capacitor (C58) to ground. The power supply pins (pins 5 and 8) are connected to a 5.5V supply.

The *Symbol Properties dialog is open, showing the General tab. The MPN field is highlighted, containing the value OPA858IDSGR. The dialog also shows fields for Name, Value, Footprint, Datasheet, and mouser.

Name	Value	Show	H Align	V Align	Italic	Bol
Name	OPA858	<input checked="" type="checkbox"/>	Center	Center	<input type="checkbox"/>	<input type="checkbox"/>
Footprint	SPIRIT:WSON-8-1EP_2x2mm_P0.5mm_EP0.9x1.6mm	<input type="checkbox"/>	Left	Center	<input type="checkbox"/>	<input type="checkbox"/>
Datasheet	http://www.ti.com/product/OPA858?utm_source=google&	<input type="checkbox"/>	Center	Center	<input type="checkbox"/>	<input type="checkbox"/>
mouser	595-OPA858IDSGT	<input type="checkbox"/>	Center	Center	<input type="checkbox"/>	<input type="checkbox"/>
MPN	OPA858IDSGR	<input type="checkbox"/>	Center	Center	<input type="checkbox"/>	<input type="checkbox"/>

General

Unit:

Alternate symbol (De Morgan)

Angle:

Mirror:

Pin Text

Show pin numbers

Show pin names

Attributes

Exclude from bill of materials

Exclude from board

Update Symbol from

Change Symt

Edit Symbo

Edit Library Syr

Octopart



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Octopart Categories OPA858 API BOM Tool F

All Parts (6)

Amplifiers - Op Amps, Buffer, Instrumentation 6

Distributor Manufacturer Lifecycle Status CAD Models Number of Pins Input Offset Voltage (Vos) Min Supply Voltage Max Supply Voltage + Add More Filters

Prices Specs Currency: GBP Sort: Relevance Availability: All 6 results | Distributor links are sponsored

OPA858IDSGT - Purchase at the lowest online price* on TI.com ti.com

Texas Instruments OPA858IDSGR GBP 2.848 + Add to BOM Datasheet at TI.com 3 CAD Models
Volt Feedback Amp Single 2000V/us 3.3V to 5.25V 8-Pin WSON T/R

Distributor	SKU	Stock	MOQ	Pkg		1	10	100	1,000	10,000	Updated
★ Arrow Electronics	OPA858IDSGR	1,096	1	Cut Tape	GBP *	5.670	5.053	3.998	2.865	2.865	<1m
★ Texas Instruments	OPA858IDSGR	3,000	1	Cut Tape	GBP *	3.380	3.380	2.755	1.837	1.837	<1m
★ Mouser	595-OPA858IDSGR	3,755	1	Tape & Reel	GBP	5.180	4.650	3.810	2.840	2.830	<1m
★ Digi-Key	296-OPA858IDSGRCT-ND	3,781	1	Cut Tape	GBP	5.320	4.780	3.916	3.316	3.316	<1m
★ Verical	OPA858IDSGR	1,096	3		GBP *		5.053	3.998	2.865	2.865	<1m

Show All Specs Descriptions Manufacturer Page Reference Designs

There are various BOM tools and plugins available for KiCAD that can find supplier part numbers and price a BOM from the MPNs in your schematic.

Component Search Engine




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<https://componentsearchengine.com>

Very useful tool to obtain
(mostly basic but usable)
Footprints, symbols and 3D
models of parts that are not in
KiCad's built in libraries
(which is very often!)

Search by keywords, technical specifications or part number Search

[← back to results](#)



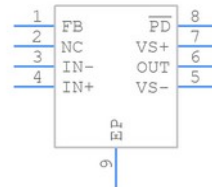
OPA858IDSGR - Texas Instruments

Description: 5.5 GHz Gain Bandwidth Product, Decompensated Transimpedance Amplifier with FET Input

[Download ECAD Model](#) [Schematic symbols](#) [PCB footprints](#) [3D models](#)

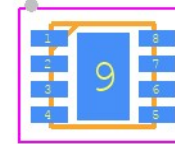
Alert me if there are changes to this model
Email notifications will be applied after download.

Symbol



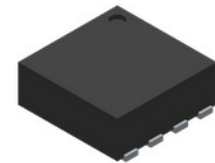
[click to zoom](#)

PCB Footprints



[click to zoom](#)

3D Models



[click to zoom](#)

Manufacturing a PCB in the UK



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Reasonably priced, fast turnaround available, online quotes that are pretty good: <https://www.pcbtrain.co.uk> (a.k.a Newbury Electronics). Can do fabrication and assembly, upload your design and BOM details and get a quote in your inbox in a couple of minutes

Product Family: 1 layer 2 layer **4 layer** 6 layer 8 layer 10 layer 12 layer Express laser stencil service Stainless Steel

Service: Standard Express

Copper Weight: (Finish Microns) 35 70

Material: FR4 (150 deg C) middle Tg

Thickness: 0.8mm 1.2mm **1.6mm** 2.4mm 3.2mm

Finish: IS ENIG

Circuit Size X x Y*: 100 X 100 mm

Solder Resist: Green Red **Blue** Black White

Legend: White Yellow

RESET NEXT STEP

YOUR ORDER DETAILS

Product Name: 4 layer FR4 (150 deg C) middle Tg 1.6mm ENIG Blue White

Supply in panels: No

Product Family:	4 layer	Copper Weight:	35
Material:	FR4 (150 deg C) middle Tg	Thickness:	1.6 mm
Circuit Size X:	100 mm	Circuit Size Y:	100 mm
Legend:	White	Solder Resist:	Blue
Service:	Standard	Finish:	ENIG
Quantity:	1		

Price in GBP, exclusive of carriage

W/Days	1 Qty	2 Qty	3 Qty	4 Qty
4	£ 425.55	£ 476.88	£ 528.21	£ 579.52
5	£ 312.71	£ 357.28	£ 401.85	£ 446.44
7	£ 278.44	£ 317.62	£ 356.79	£ 395.96
10	£ 227.04	£ 258.10	£ 289.17	£ 320.24
15	£ 184.21	£ 208.52	£ 232.83	£ 257.16

Manufacturing a PCB in the UK



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A range of more expensive & boutique manufacturers who can do more custom things and guarantee to verified IPC quality levels, including electrical test etc.

Careful, these get very expensive very fast.



Word of warning: **express circuits**, whilst a very good manufacturer (in my experience), now **REQUIRES** your data in non-gerber format, and as such right now it is **hard, though not impossible** to directly send them designs from KiCad.

This will improve within a few months hopefully.



Recommendation for “boutique” manufacturer: Cambridge Circuit Company.

Cost typically ~2-3x as much as Newbury

Manufacturing from China



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Chinese “prototype” level manufacturers, including e.g. JLPCB and OSHPark should **not be discounted**. The manufacturing quality is typically very high, and cost much lower than UK manufacturers. Shipping is generally not that bad either. **However**, be prepared for them to manufacture **exactly** what you send them, mistakes and all!

You will not get an email saying “are you really sure you want this”?

Example: my personal favourite based on experience, SeeedStudio fusion (<http://www.seeedstudio.com/pcb-assembly.html>)

(Right: ~same spec as Newbury/PCBTrain)

Newbury: 10 off in 10 w/days £506.60

Seeedstudio: 10 off in 7 w/days (then shipping): \$130 ~ £103 (+ shipping)

PCB Cost	USD\$129.90
Base Material	FR-4 TG130
No. of Layers	4 layers
PCB Dimensions	100mm * 100mm
PCB Quantity	10
No. of Different Designs	1
PCB Thickness	1.60mm
PCB Color	Blue
Surface Finish	ENIG
Minimum Solder Mask Dam	0.1mm↑
Copper Weight	1oz.
Inner Copper	0.5oz.
Minimum Drill Hole Size	0.3mm
Trace Width / Spacing	6/6 mil
Plated Half-holes / Castellated Holes	No
Impedance Control	No
Sub-Total	USD\$129.90
Production Time ⓘ	5 ~ 7 Working Days
Weight	0.32kg
Shipping	Calculated at Checkout

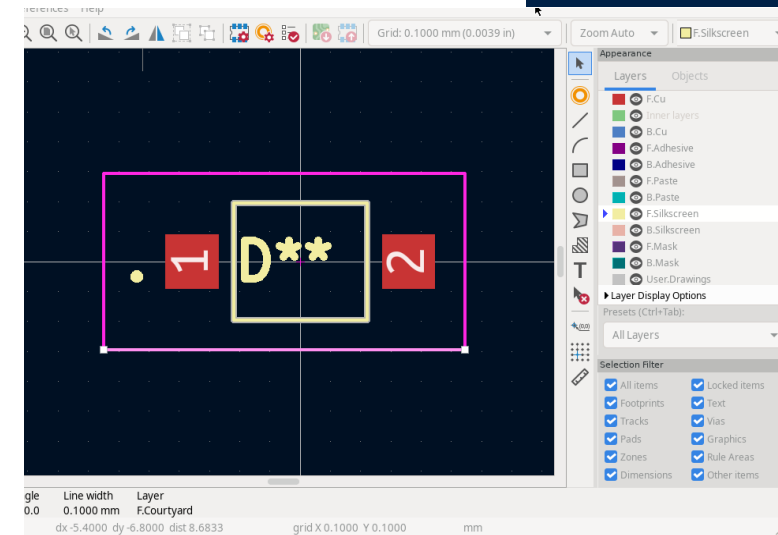
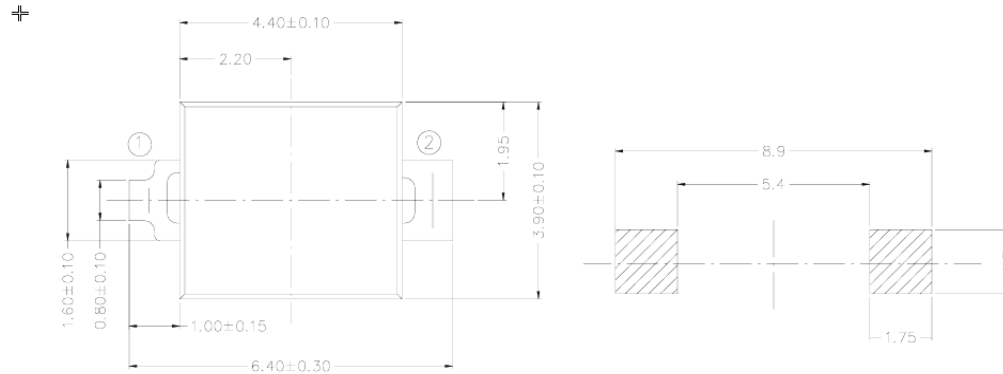
[Add to Cart](#)

KiCad part creation example



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Drawing & Land pattern from datasheet (VBPW34FAS)

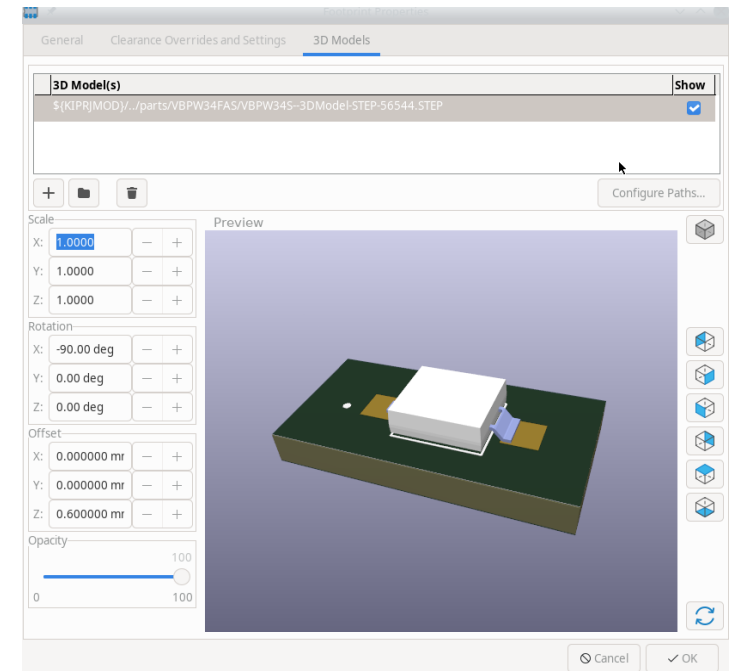


Below:
Use “generic” symbol,
And associate MPN,
Footprint and BOM data in schematic

Name	Value	Show
Reference	D1	<input checked="" type="checkbox"/>
Value	VBPW34FAS	<input checked="" type="checkbox"/>
Footprint	cosmic_ray_detector_lib:VBPW34FAS	<input type="checkbox"/>
Datasheet	https://componentsearchengine.com/Datasheet	<input type="checkbox"/>
Description	PIN Photodiode 780-1050nm SMD2 GW Vishay	<input type="checkbox"/>
Height	1.4	<input type="checkbox"/>
Manufacturer_Name	Vishay	<input type="checkbox"/>
MPN	VBPW34FAS	<input type="checkbox"/>
Farnell	1779701	<input type="checkbox"/>
Mouser	782-VBPW34FAS	<input checked="" type="checkbox"/>

Above right:
Draw (or download)
footprint and
CHECK against
datasheet

Below Right:
Download (or draw!!!) 3D
model for MCAD
integration



Kicad Schematic Tips



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This applies not just to KiCad but schematic drawing for “real” PCBs in general.

- A schematic for an actual, real PCB that will be built is quite different from the “conceptual” schematic you jot down on paper or see in a textbook. The “little details” are important
- Any reasonably sized schematic doesn’t nicely fit on one page, and though it’s personal preference I like my schematic pages to not be too crowded.
- KiCad supports multi sheet design in two ways: **flat** multi-page designs with global labels, and **hierarchical** designs with hierarchical labels. I prefer this latter and again that’s personal preference but for the purposes of today this is how we will look at it.
- Associate as much data with the schematic before layout as possible, this includes: footprints, BOM data, datasheets and netclasses.
- Just like writing a computer program, put **text** comments on your schematic to indicate intent.
- Make sure to **label** important nets with useful names so you can easily see them whilst in layout

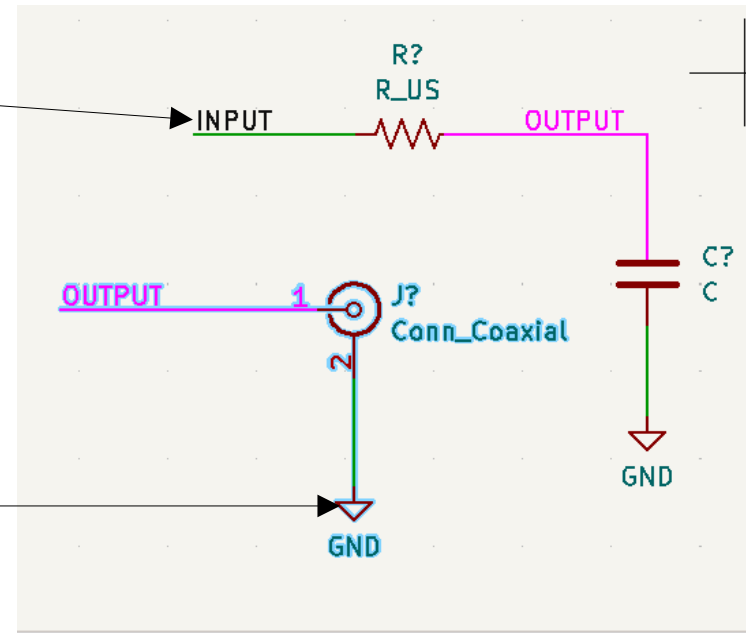
Schematic Labels

Normal labels: the two nets labelled "OUTPUT" are **electrically connected**

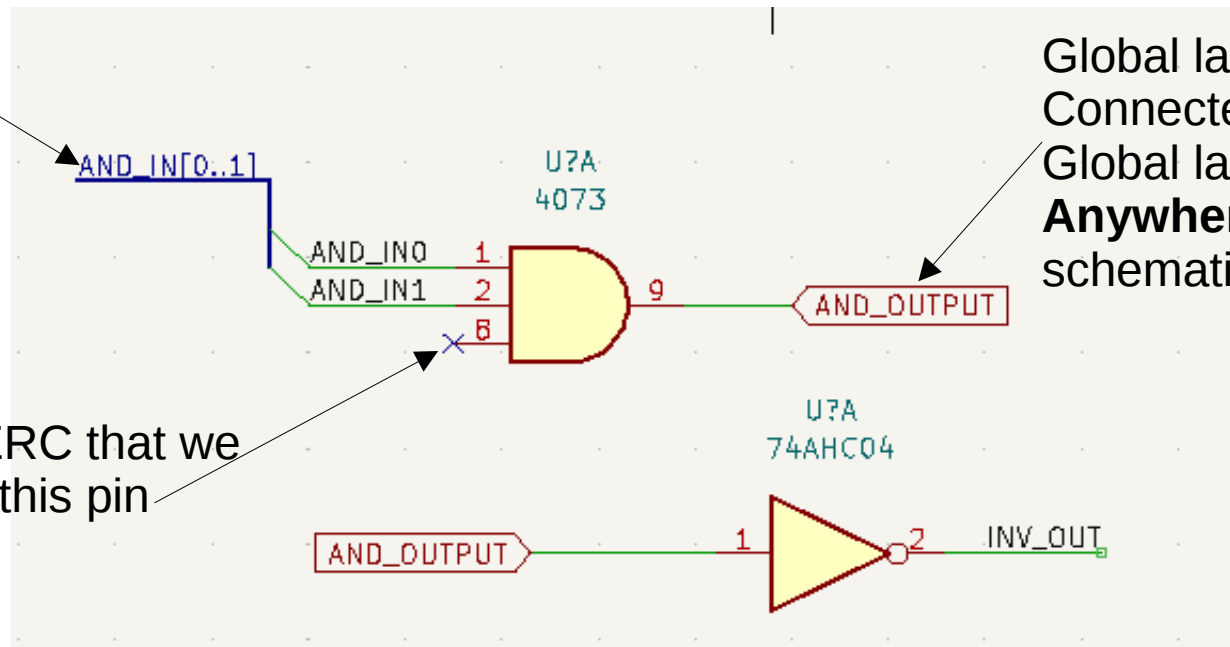
(this is common in most modern PCB Software, simplifies schematic spaghetti).

But, ONLY if they are on the same sheet!

ALL power symbols (e.g. "GND") with The same name are connected **globally** Throughout the schematic.



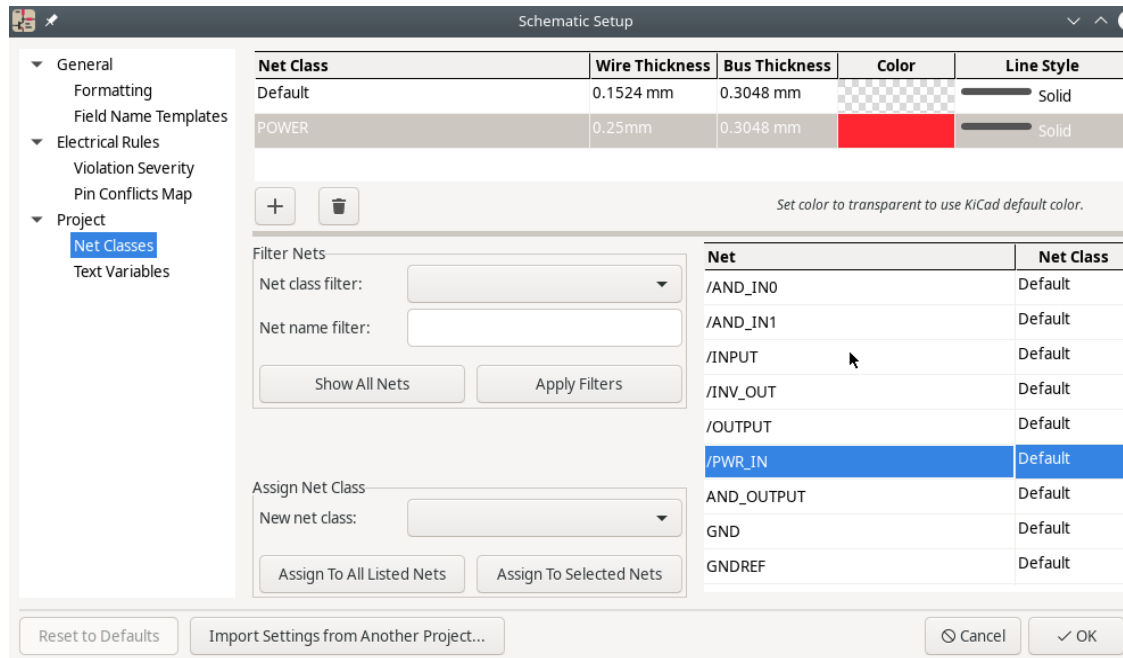
Buses – groups of similar signals



Global labels - Connected to Global labels of same name **Anywhere** in a multi-page schematic`

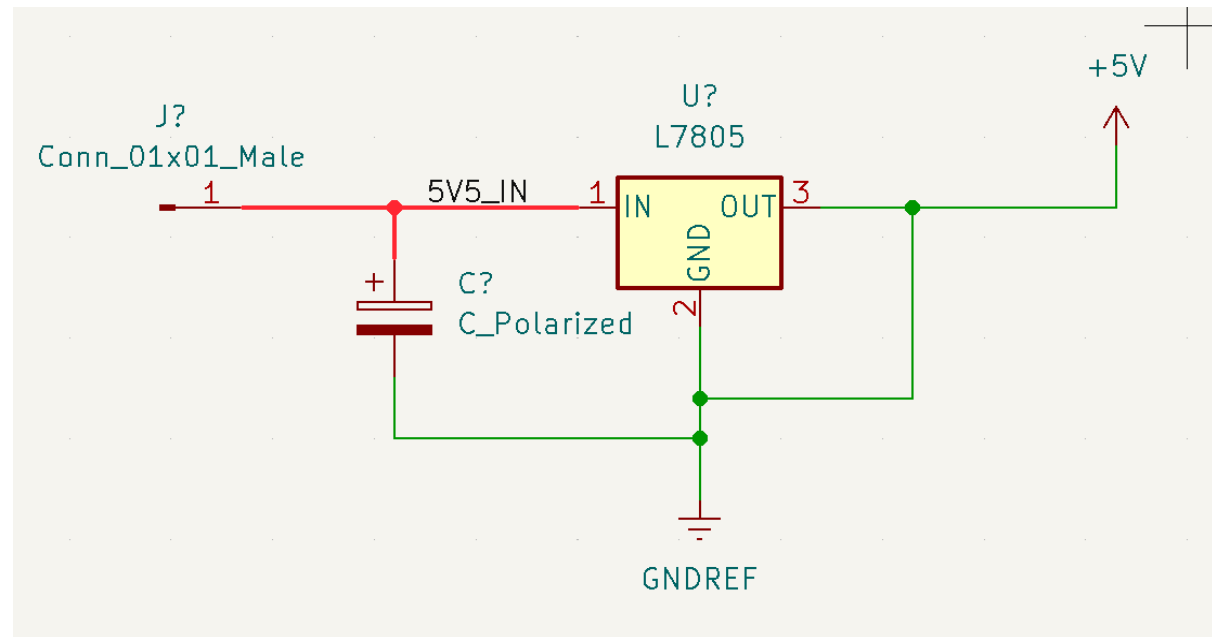
NC symbol - Indicates to the ERC that we Will not be using this pin

Netclasses

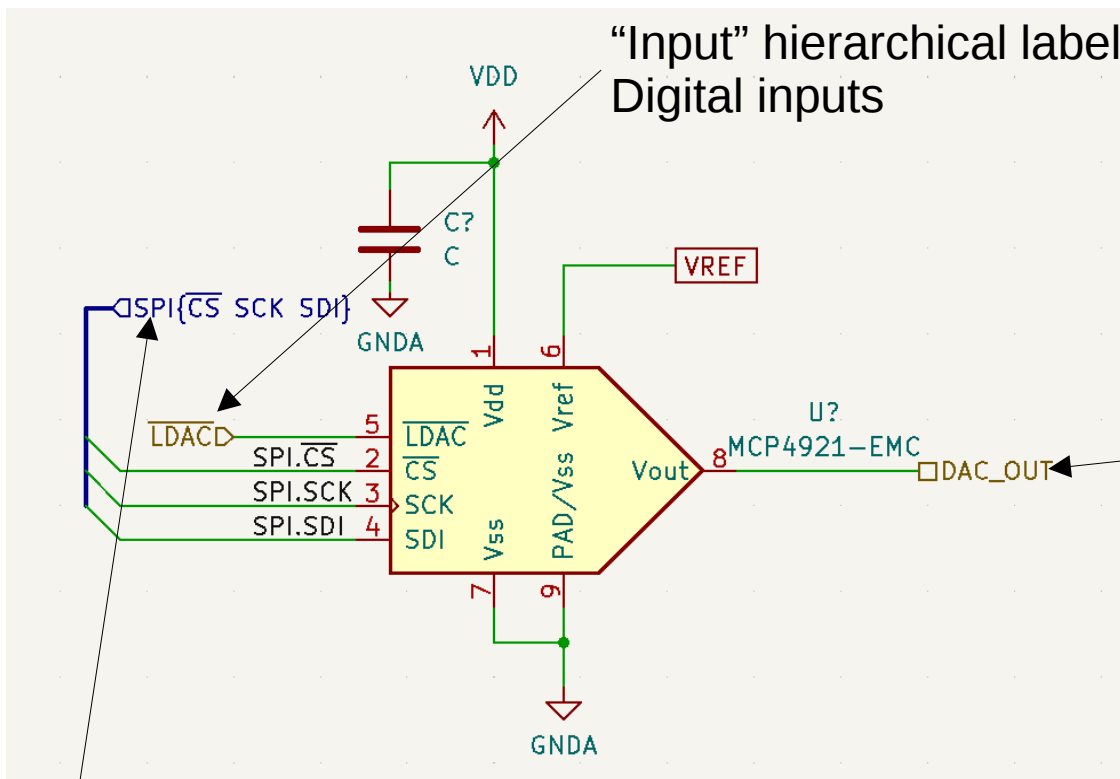


Netclasses are just “types” of net, that we might want later for PCB routing purposes (e.g. to make all power input nets have thicker and more separated traces). We set them up in the “Schematic Setup” dialog

Right: We have assigned the “5V5_IN” net to the POWER netclass, this gets transferred to the PCB routing



Hierarchical Schematics



“Input” hierarchical label – for Digital inputs

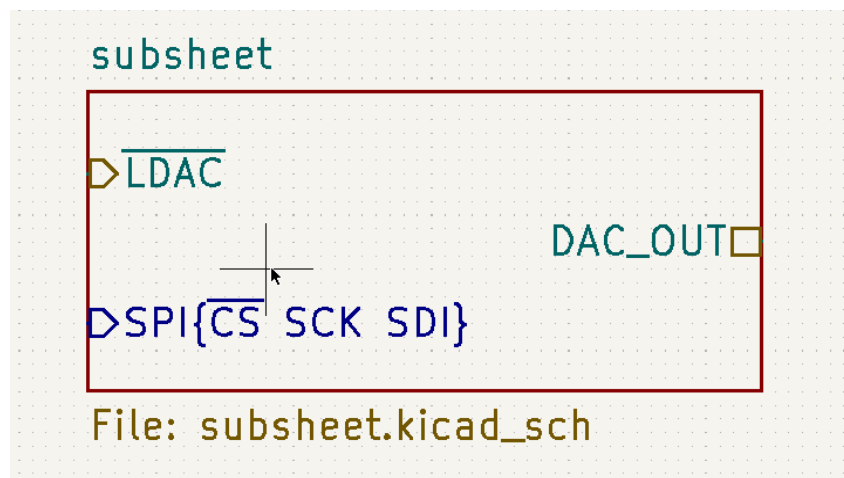
Hierarchical Labels – connect Through sheet symbols. (left) – the contents of “subsheet.kicad_sch”.

“Passive” hierarchical label use for all analog signals

Below: the top level sheet. Each hierarchical label in the subsheet appears here. We can connect wires and buses to them as though the sheet were a component

Group Bus – groupings of named Nets inside a bus (but not numbered) – useful for well defined interfaces e.g. SPI, I2C, UART etc

Hierarchies can be as deep as needed. You can also use the same schematic File in multiple sheet symbols if you need “suplicated” subsystems in the design



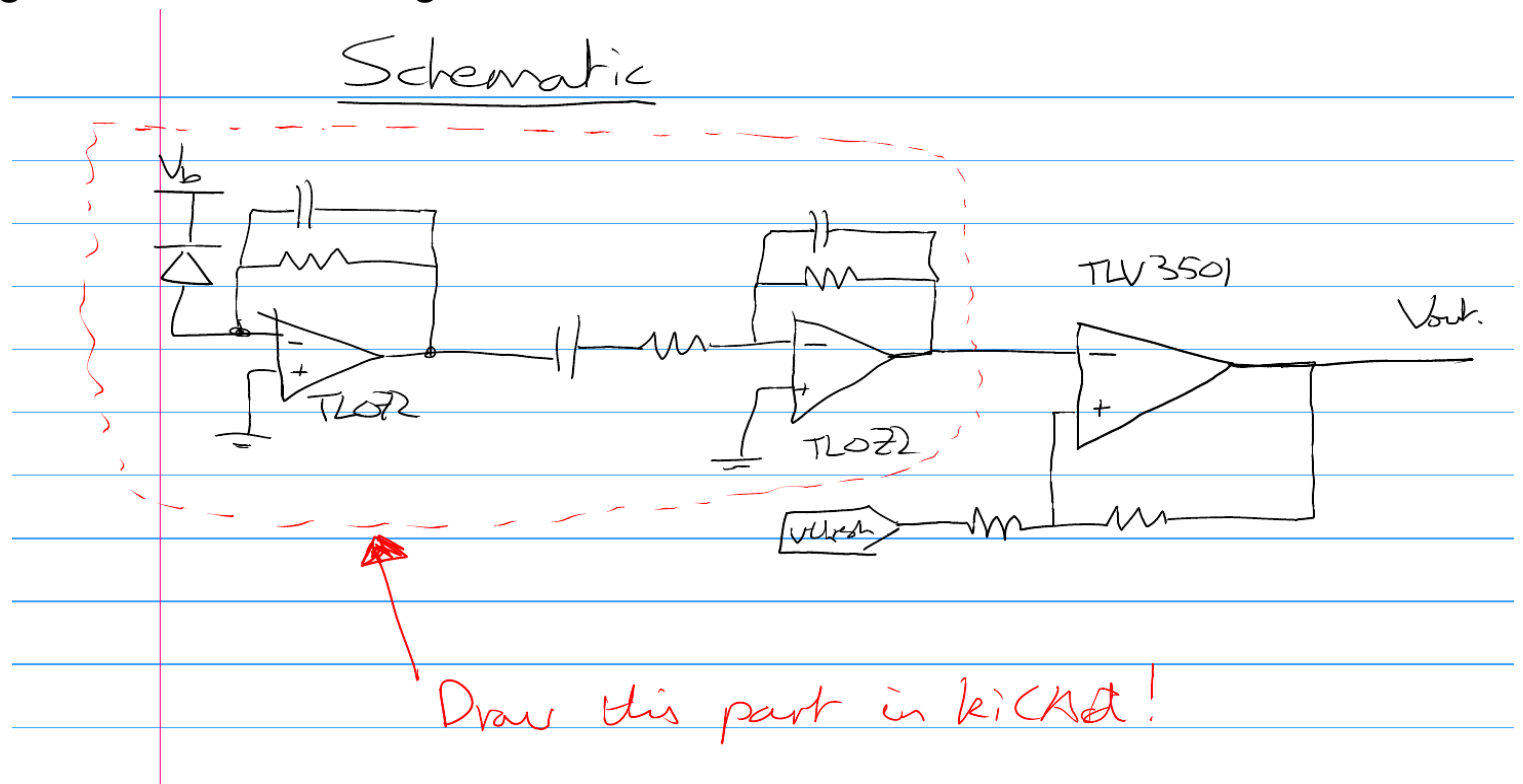
Walkthrough KiCad Schematic

On the Indico page, you will find two .zip files:

1) a KiCAD project for a “PIN diode based gamma ray detector” which has a pretty complete schematic, including data for parts, MPNs, footprints etc “schem_proj_complete.zip”

2) the same project but with a crucial part of the schematic missing – the frontend for the detector! The challenge is to draw in the missing part of the schematic. “schem_proj_nofrontend.zip”

We will talk through how to do this together to learn some of the KiCad basics.



Schematic Steps Overview



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- 1) Draw basic circuit** – the symbols should all already be included in the project in the “cosmic_ray_symbols” library
- 2) Label & connect** – add suitable net labels and connect the new sheet into the hierarchy properly
- 3) Annotate** – annotate the schematic (assign specific designators to each part)
- 4) Pass ERC** – run the ERC and tweak until there are no more errors!
- 5) Assign Footprints & add BOM data** - associate each schematic symbol to a physical footprint and part to order
- 6) Assign netclasses** – We will assign some netclasses for traces like “power” and “bias” to associate custom design rules with them at layout time
- 7) Set up sheet block and export drawings for review**

Thanks!



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To be continued on Friday where we get to the fun part – layout!

Questions, comments etc greatfully received:

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This lecture is brand new for the first AITL series, all feedback is VERY USEFUL!

Very happy to be contacted about “stupid questions” re: KiCad or any PCB designs. I’ve done somewhere around 30 over the years now (in KiCad, altium, Eagle, DipTrace- urrrgh) so do know a little bit about what I’m doing