Magnetovision 2D 256: Hall Array for Tokamak Field Imaging

Sam Shelton, January 2025

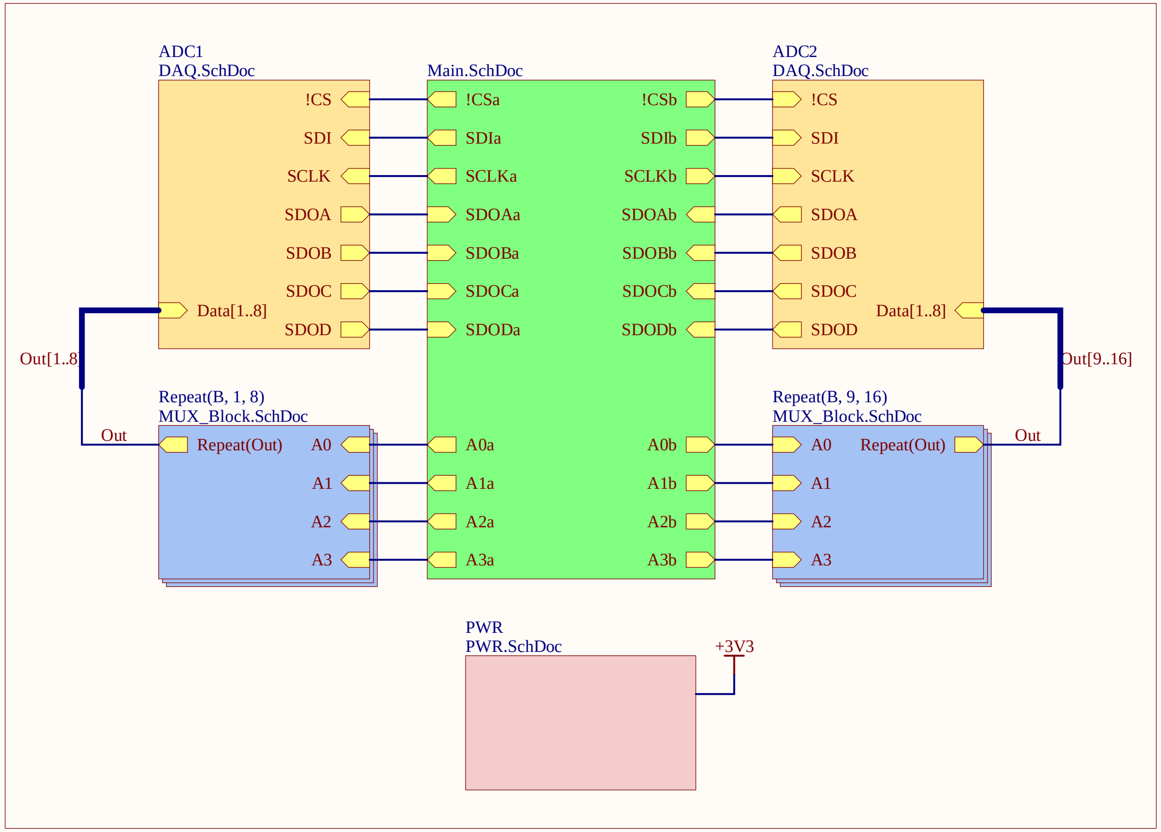
An array of 256 off-the-shelf Hall Effect sensors capable of measuring to ± 169 mT at 40 kSPS, to be used to image the field of UNSW's Tokamak

This PCB contains the sensors, filters and ADCs, as well as an LDO for power. It interfaces with another control board using level shifters and a SYZYGY FPGA Connector.

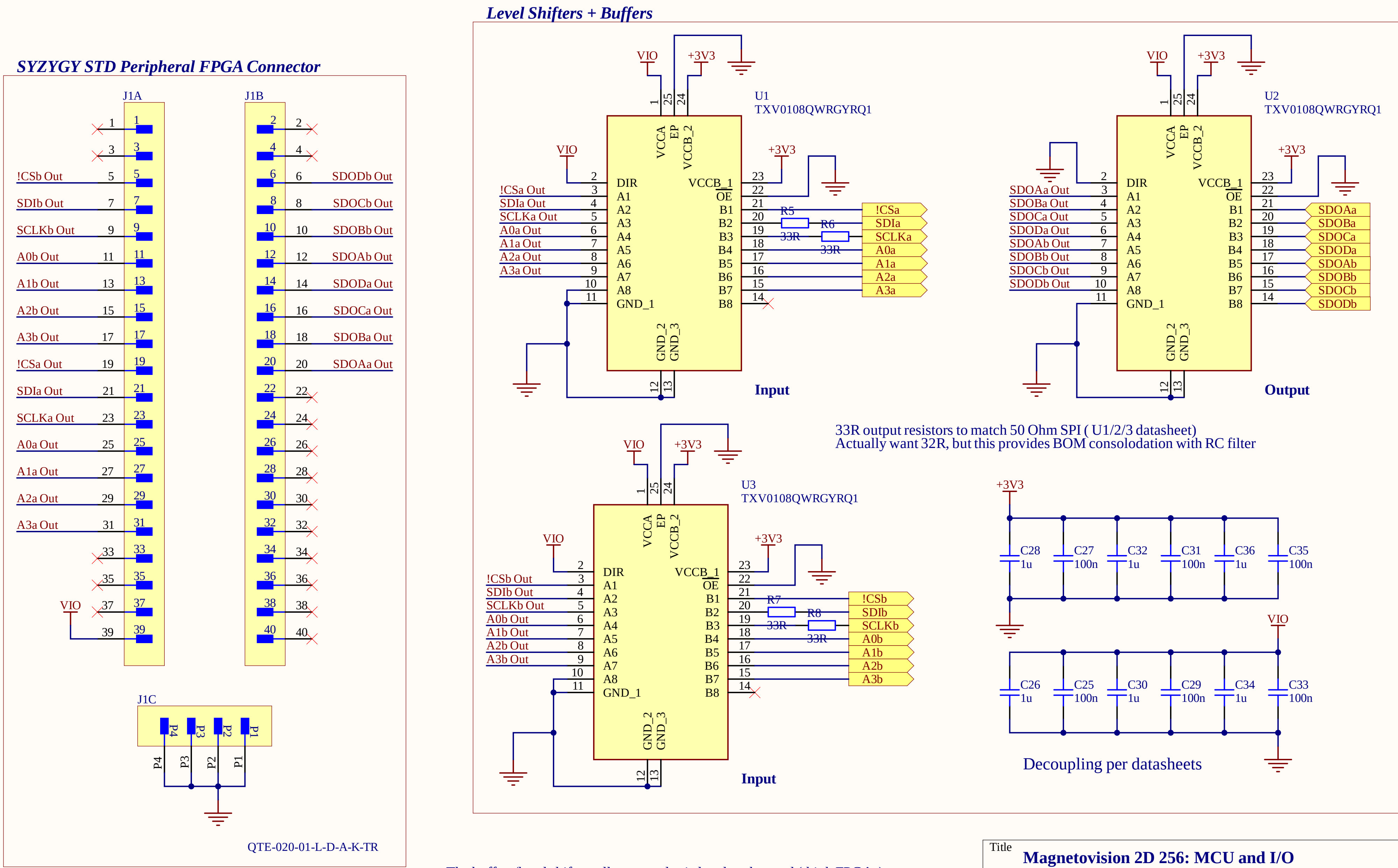
Two ADCs sample from 8 lots of 16 MUX'd sensors, allowing for simulatnious sampling of 8 sensors at a time to achieve 40 kSPS. An FPGA is required to get the full sampling rate, but a microcontroller can drive up to 4 kSPS. The sensor can operate a 60 SPS in `real-time' mode, and use hardware oversampling and/or averaging to reduce noise.

The PCB is a 6-layer board designs to use JLCPCB's advanced PCB product. It heavily uses via-in-pad and benefits from the ENIG finish. The board has SMD parts on both sides.

Schematic Overview



Title	Magnetovision 2D 256: Overview		
Size A4	Number		Revision **Final**
Date:	6/16/2025	Sheet 1of 7	
File:	C:\Users\..\Master.SchDoc	Drawn By: Samsh	



The buffers/level shifters allow more logic levels to be used (think FPGAs)
as well as buffer the relatively high-capacitance MUX control busses,
allowing them to be effectively driven by potentialy wimpy digital logic signals.

Title	**Magnetovision 2D 256: MCU and I/O**	
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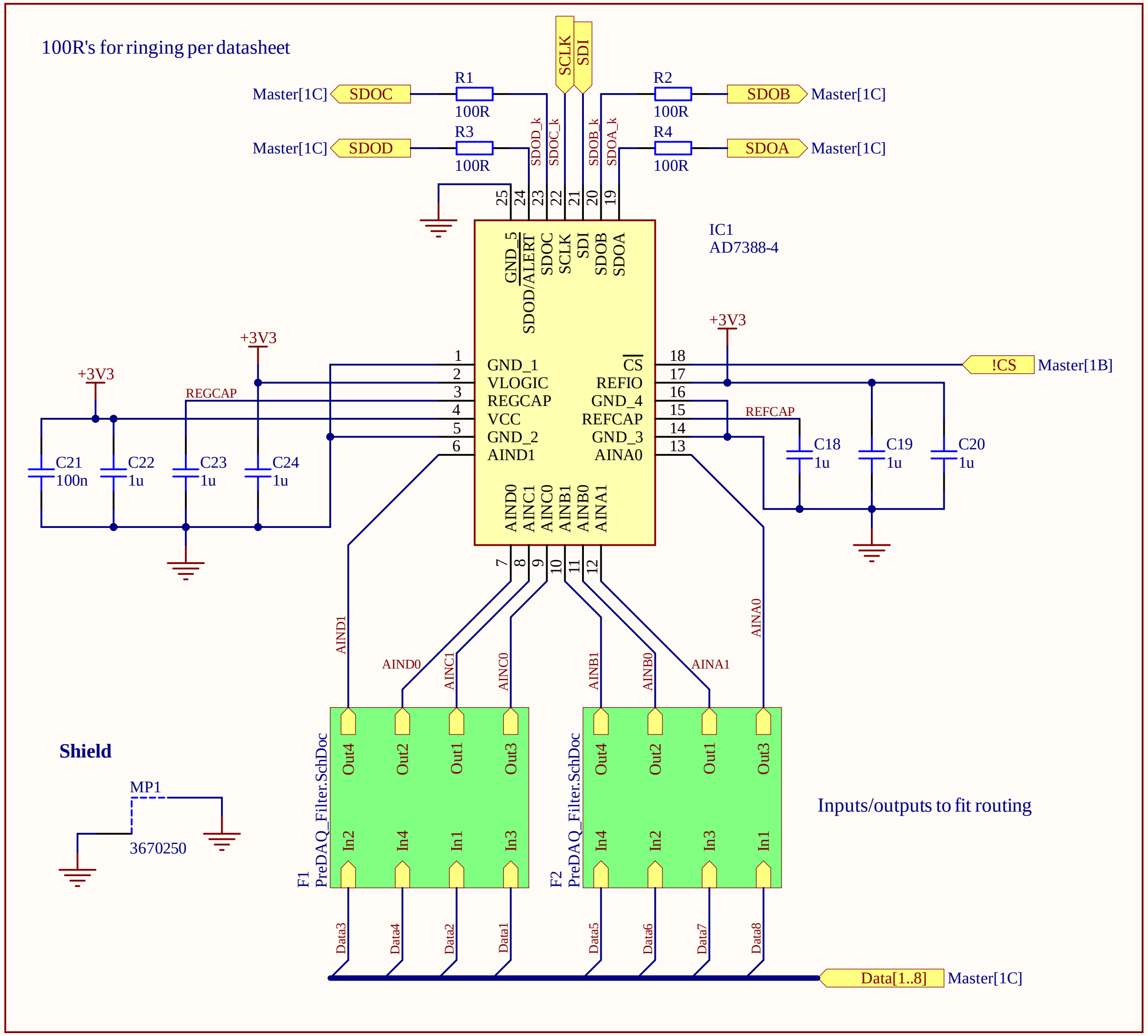
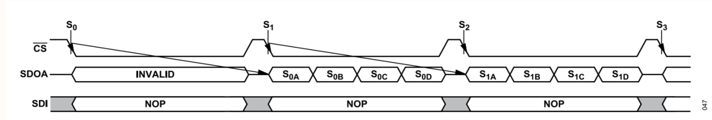
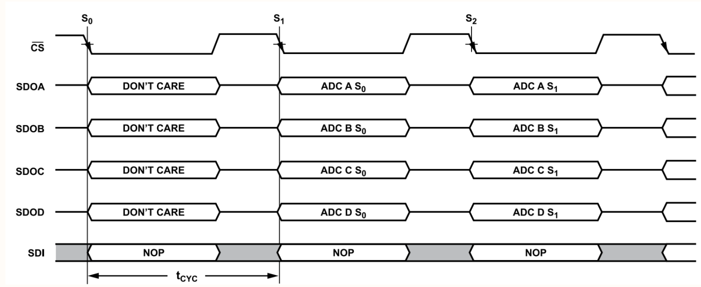
ADC and Related

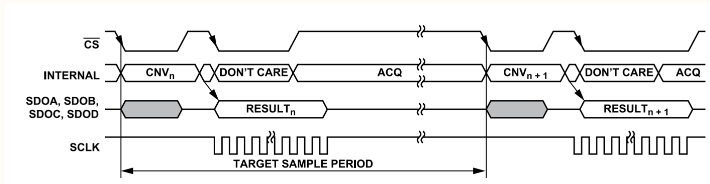




SPI Behaviour 1-Wire mode (MCU)



SPI Behaviour 4-Wire mode (FPGA)



Low Latency Mode (Realtime Operation)

SPI Note - IMPORTANT!
Note that you need to use seperate SPI busses for each ADC on the seperate control board.
This is because the level converter/buffers are not open drain/collector: they cause collisions.
This is trivial to impliment on a Teensy MCU, but still a bit annoying.

The AD7388-4 is a 12-bit part, this could be substituted for the 14 or 16 bit parts if desired (the AD7387-4 and AD7376-4 respectively - same datasheet!).
These higher bits cost more, and there is diminishing returns as they just quantise noise. These parts support hardware oversamping for a +2 bit resolution boost.
This family of parts was selected because of simultanious nature, high sample rate and support for an external reference V_ref = V_cc .
Note that the SPI behaviour of the AD7388-4 part does not quite match the behaviour of the AD7386-4 described in the datasheet. It takes 48 SCLKs to transmit all data.

In observations, RMS noise is about 0.07 mT with P2P noise of about 0.5 mT, when operatig in 60 Hz mode with 8-measurement averaging.

Title	**Magnetovision 2D 256: ADC and Related**		
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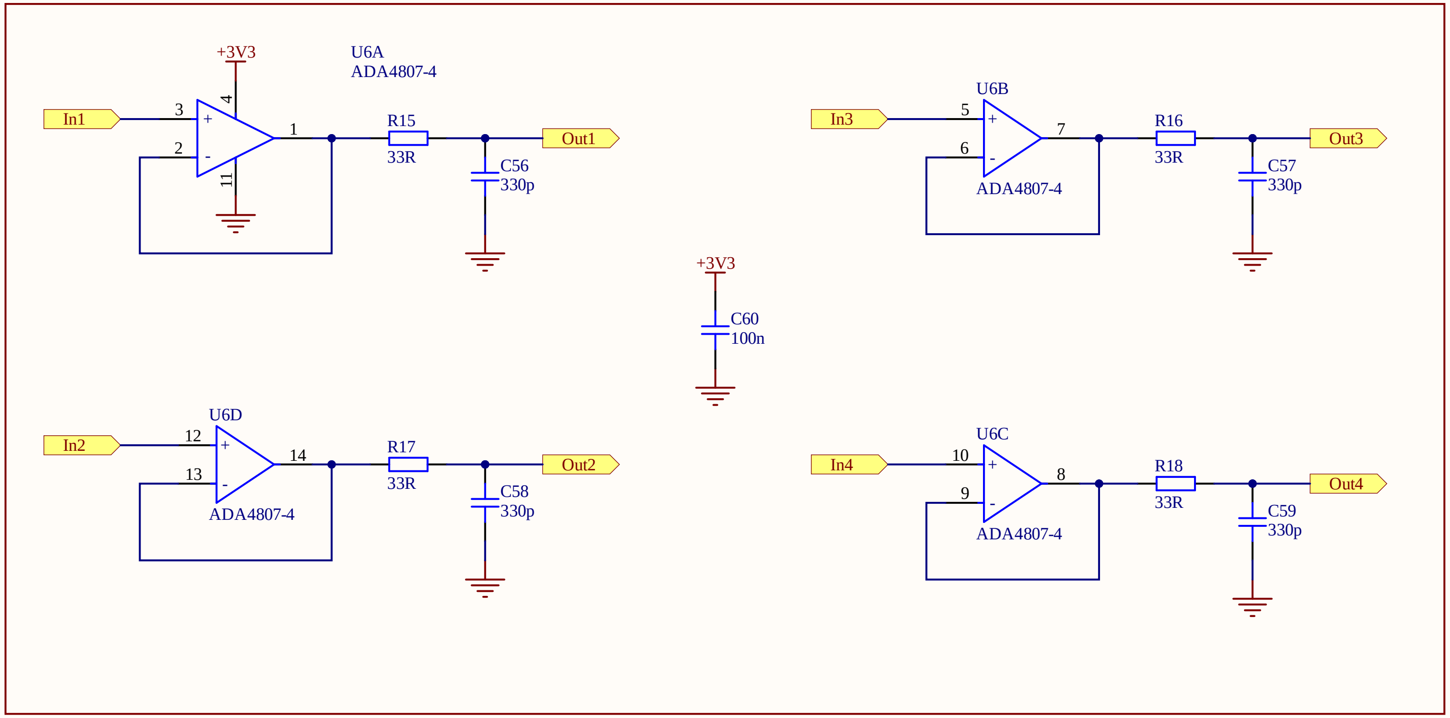
ADC Driver with RC Filter



The RC here is simply from the ADC datasheet. This is using the same (recommended) Op-Amp as the other filter, but here in a quad package to fit inside the shielding can.

We can calculate f_p = 1/(2 pi R C) = 14.6 MHz

Title	Magnetovision 2D 256: Pre-ADC Filter		
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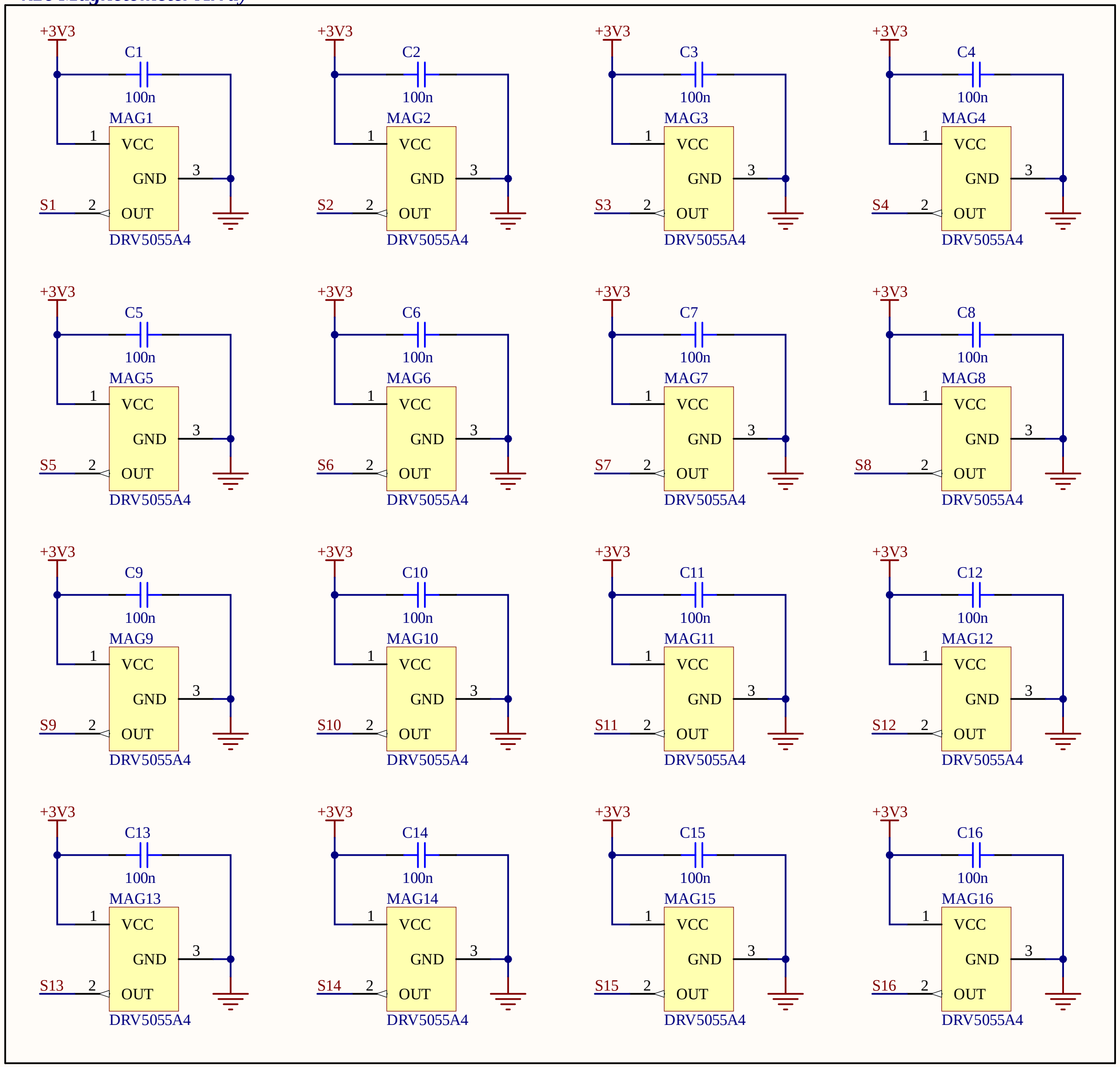
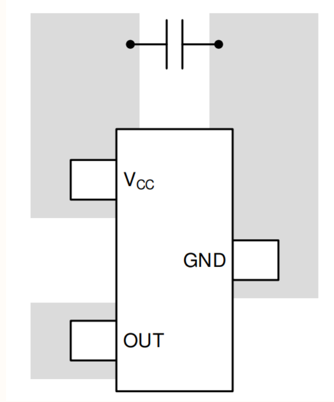
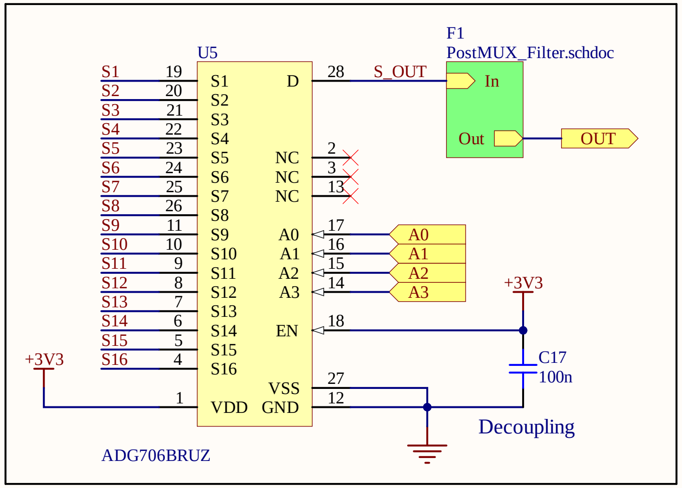
x16 Magnetometer Array



Datasheet Layouts



MUX and Related



20 KHz Sensing Bandwidth

Atomcraft has B_max = 0.125 T, requiring the X4 SKU, choose A4 for temperature drift compensation

V_out = VCC/2 + ~B, so between VCC/2 and VCC for positive B

Title	**Magnetovision 2D 256: x16 Sensor Array and MUX**		
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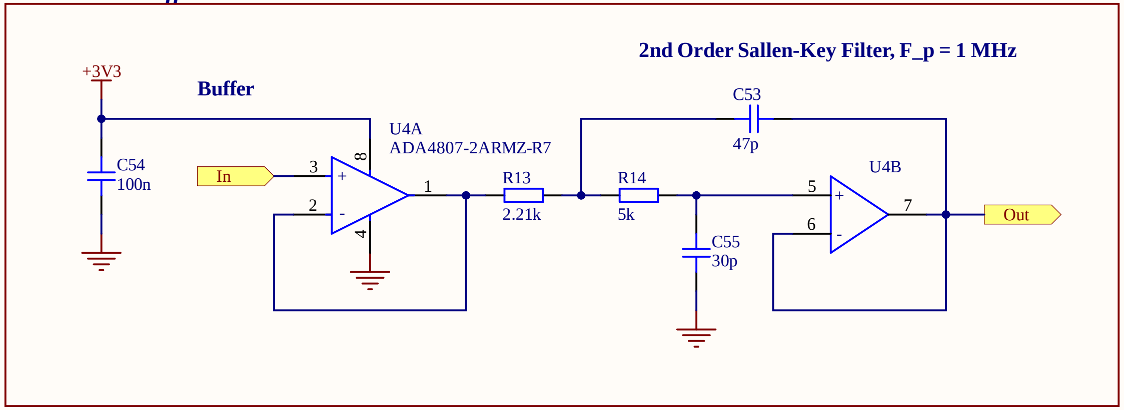
Post-MUX Buffer + Active Filter

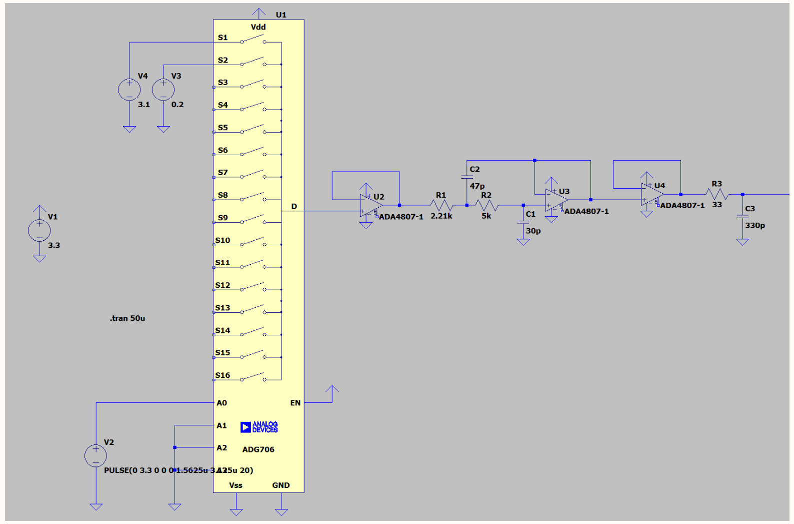


MAX ADC Speed is 2MSPS (when MUXed), so set stopband at Nyquist 1 MHz (-3db).
Used AD Filter design tool, set for Bessel topology. Adjusted R/C for manufacturing.

This particular Op-Amp is high-bandwidth AND rail-to-rail.
It was the only `recommended' Op-Amp to be stable in Spice simulations.

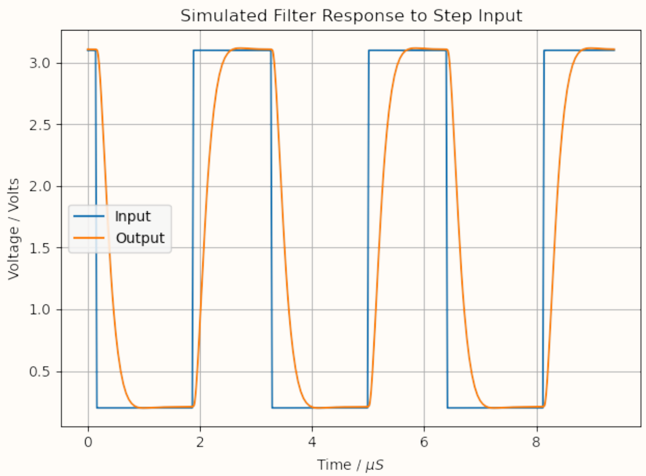
While Nyquist was a concern, the primary focus was filter settling time.
This design allows 5 tau to be achieved for all samples at 40 kSPS overall sampling.
This is just about the `strictest filter' that meets this condition with this number of stages.
More stages would have likely added more noise and introduced delay, for only midly reduced settling time.

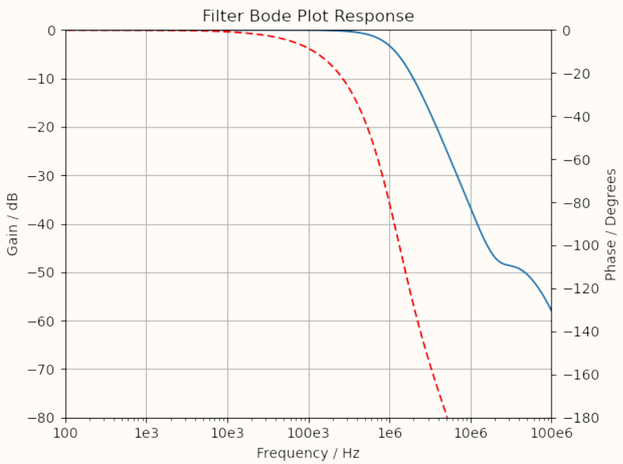
Filter Model



Filter Behaviour Simulation Results & Notes

The filter was simulated in LTSpice extensively. Analysis with an oscilloscope confirmed approrpriate filter behaviour in testing.





Title	Magnetovision 2D 256: Post MUX Filter		
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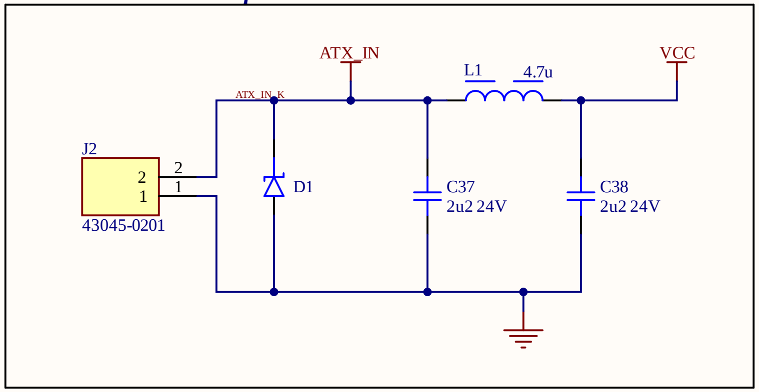
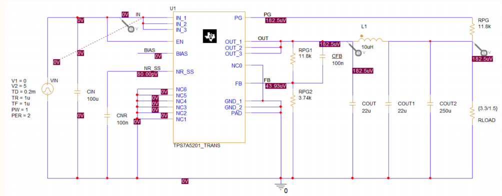
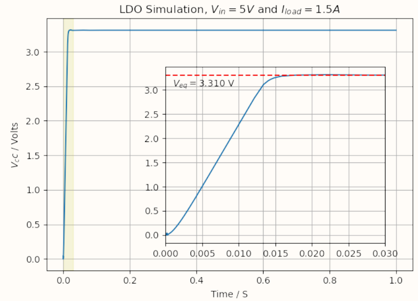
MOLEX Micro-Fit Input + Protecton + Pi Filter



Notes on Power Consumption & Behaviour

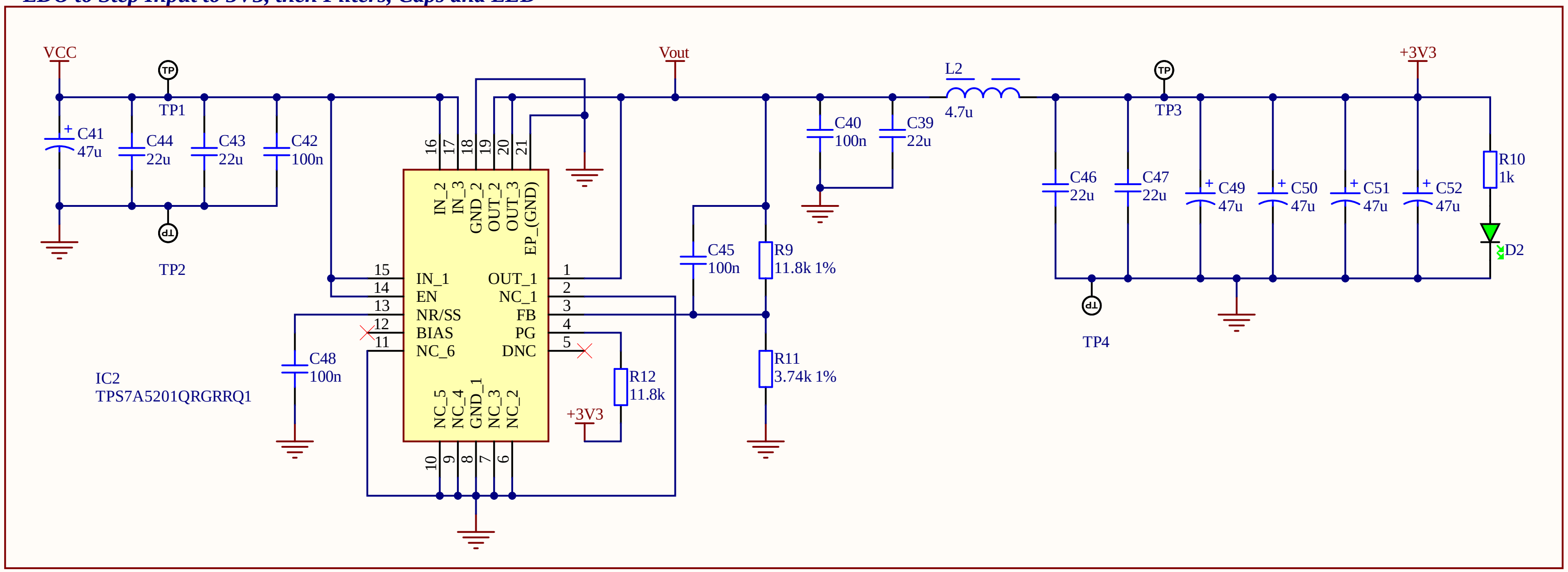
The device consumes about 1.5 A (running from 4V) and produced a fair amount of heat.
It should be allowed to sit for ~20 minutes to thermally equilibraite before callibration.
The filters seem OK at removing high frequency switching noise, but 50 Hz bleeds through.
It is recommended to power from 4V/Linear lab PSU, altough 5V is acceptable as well.





PSpice sims show good stability and ~0.020s power-up time stepping from 5V at 1.5 A load.

LDO to Step Input to 3V3, then Filters, Caps and LED



Title	Magnetovision 2D 256: Power Supply	
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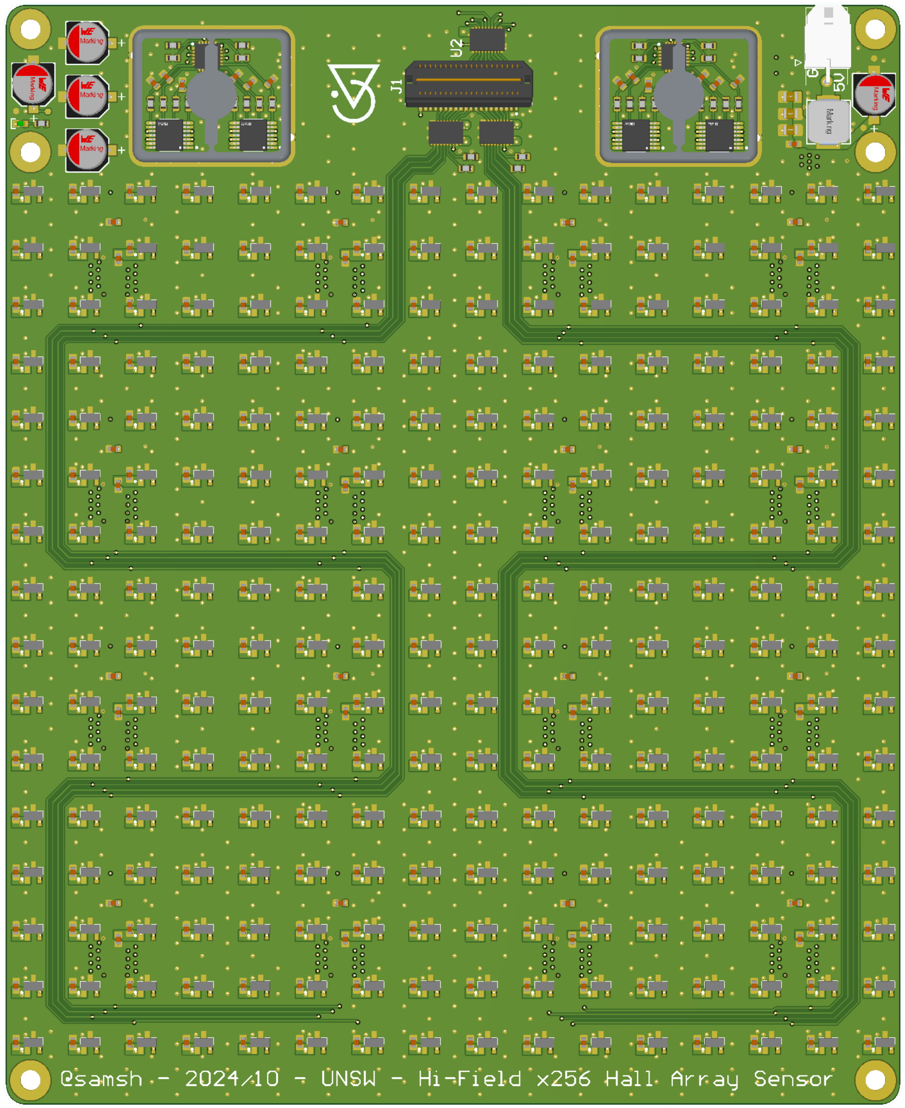
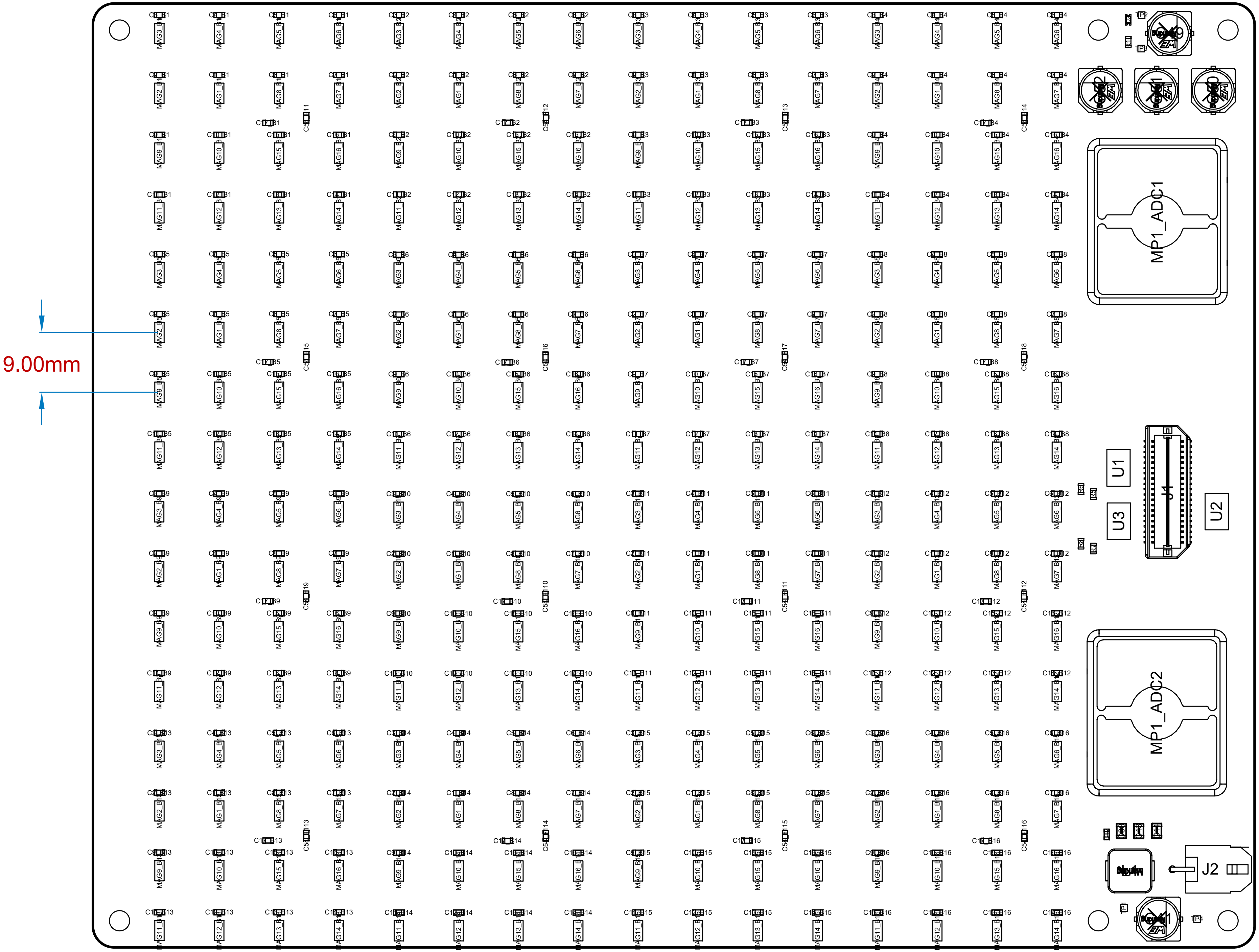
Magnetovision 2D 256: Hall Array for Tokamak Field

Sam Shelton, January 2025

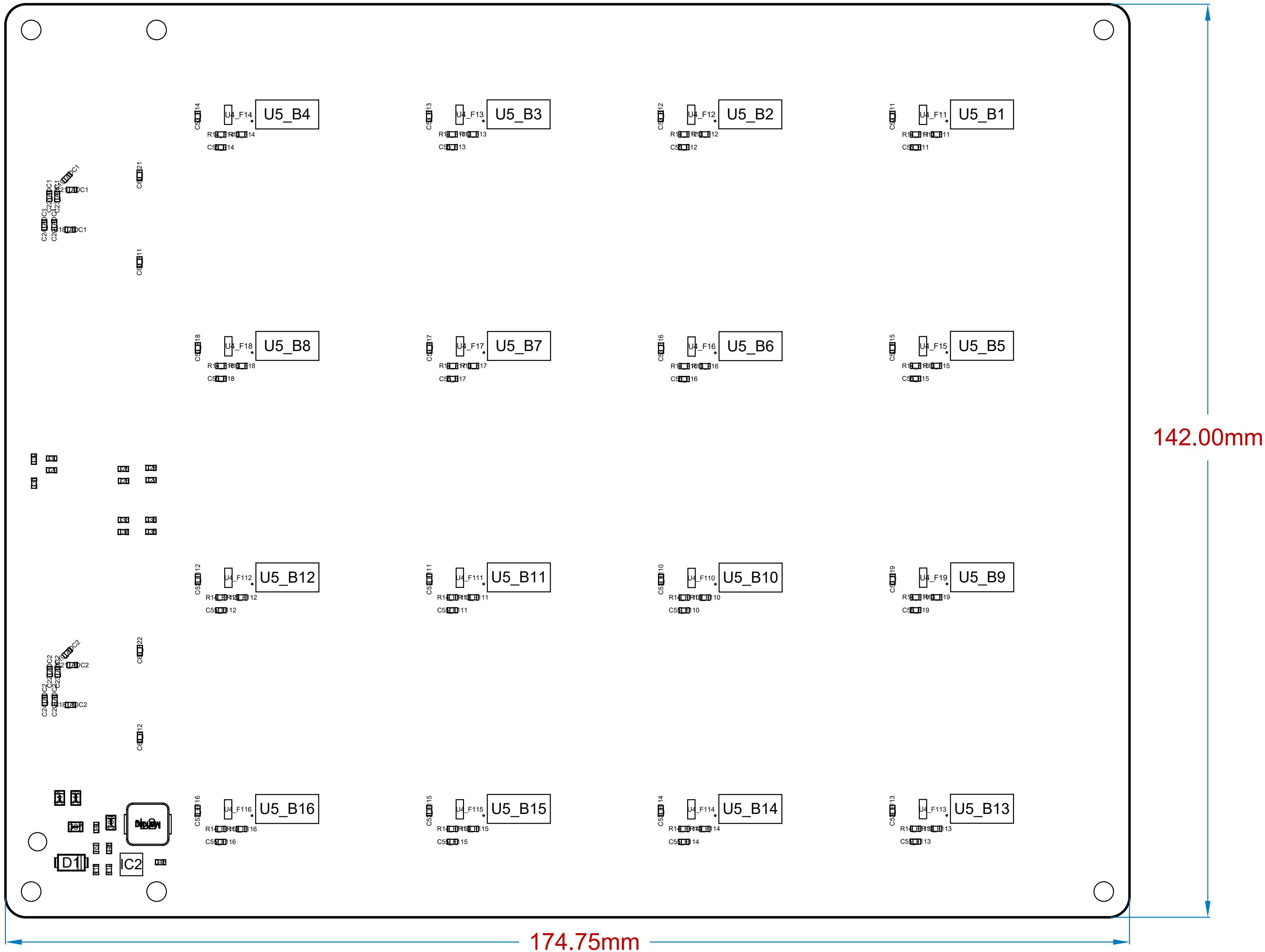


MANUFACTURING AND DISPLAY DRAWINGS

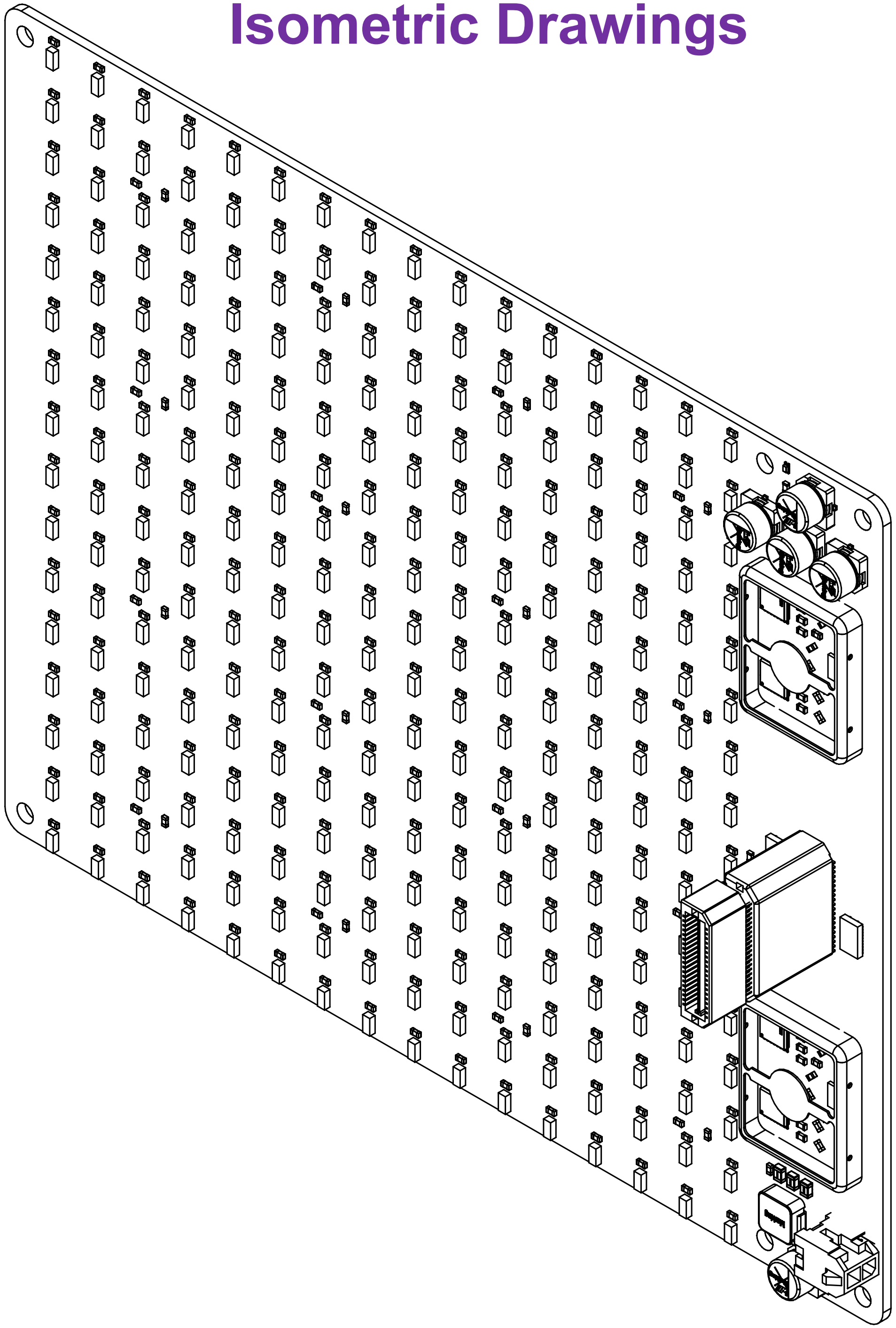
Assembly Drawing: Top View

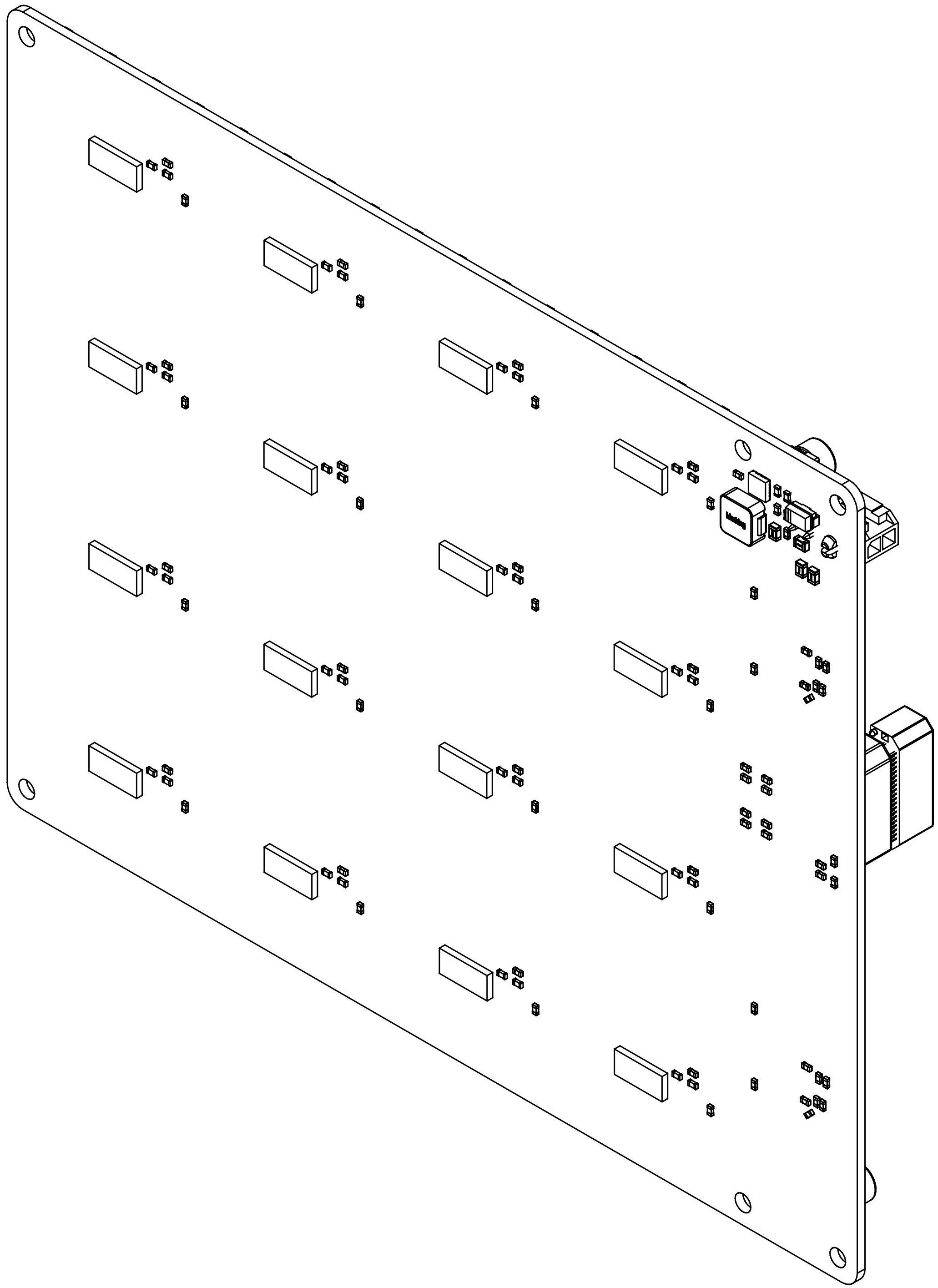


Assembly Drawing: Bottom View

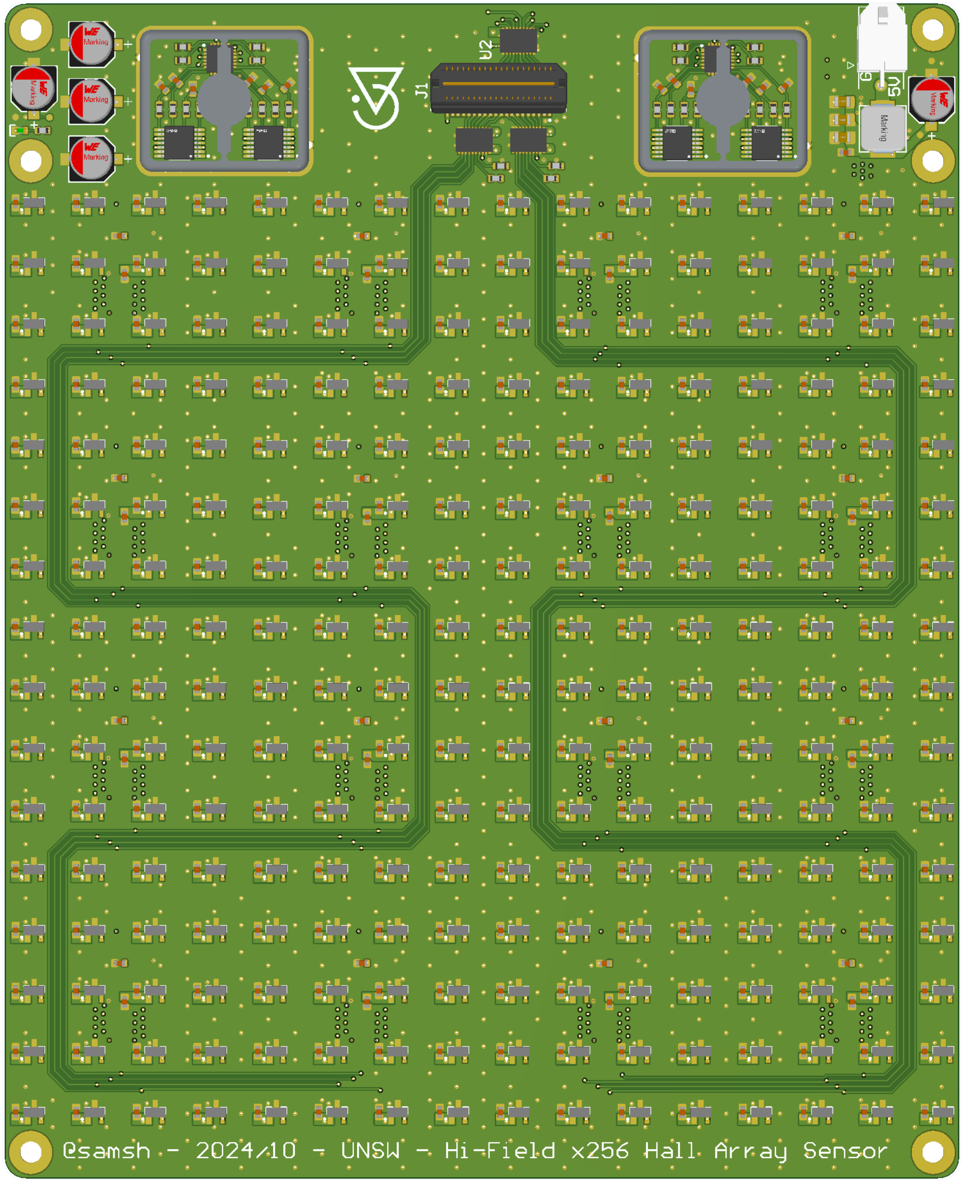


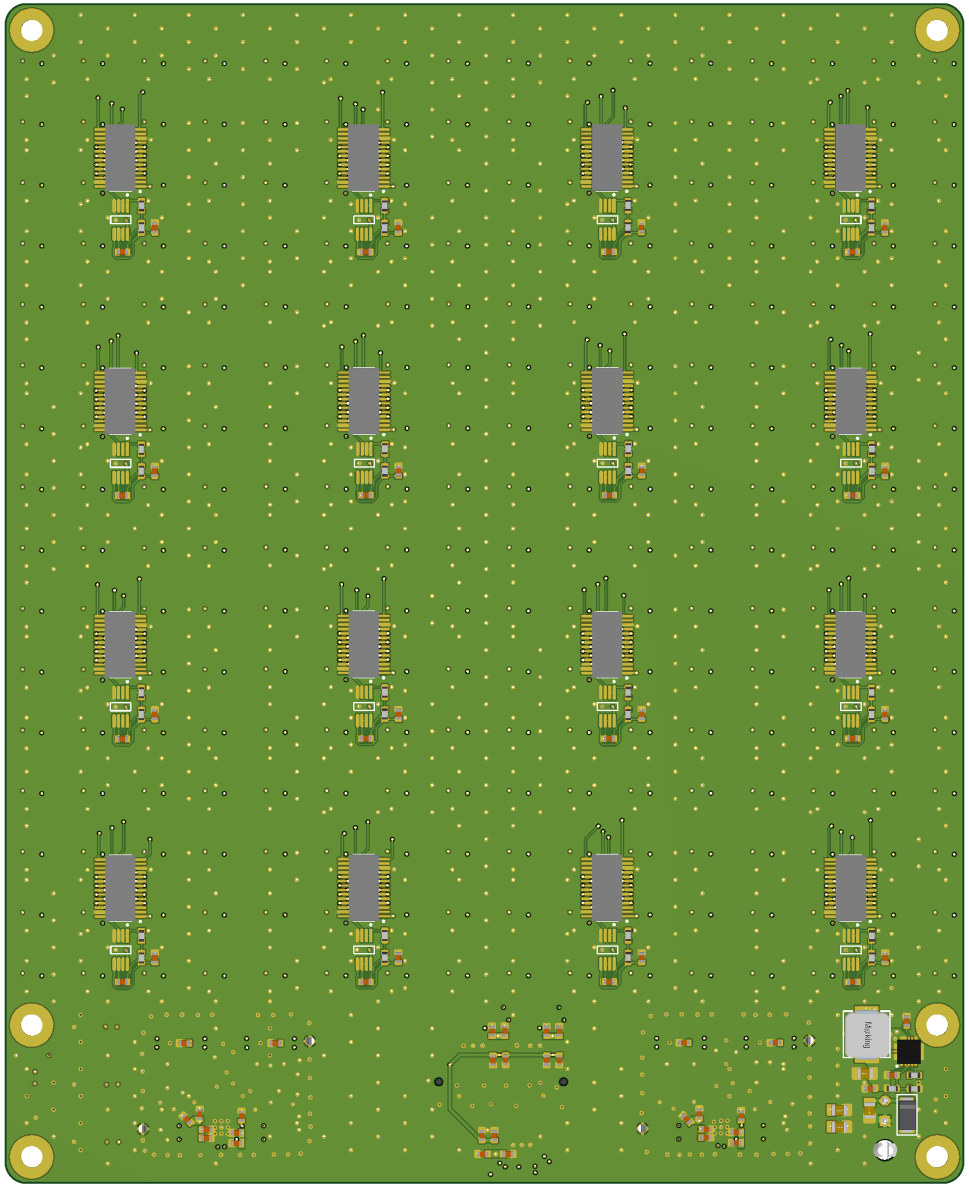
Isometric Drawings



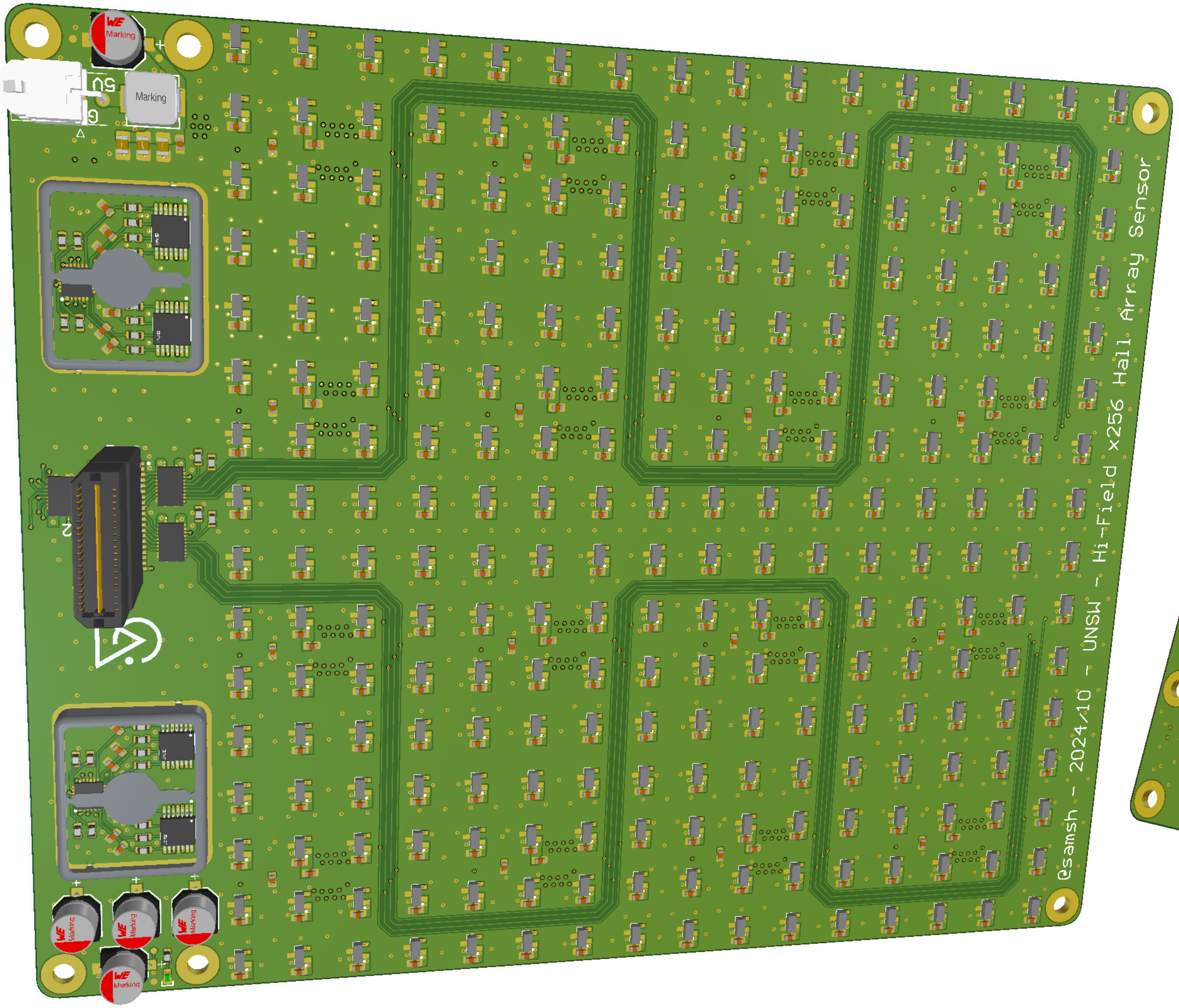


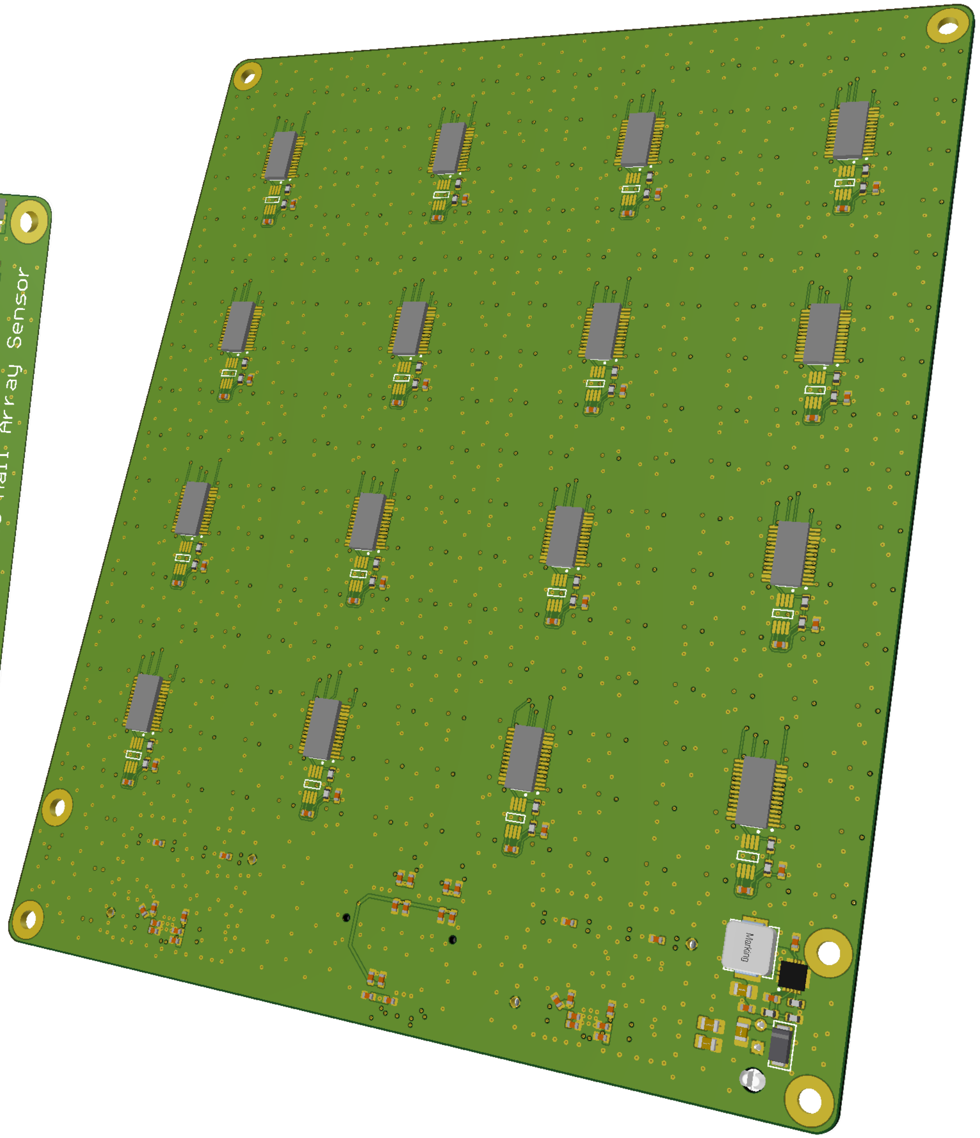
Realistic Face Drawings



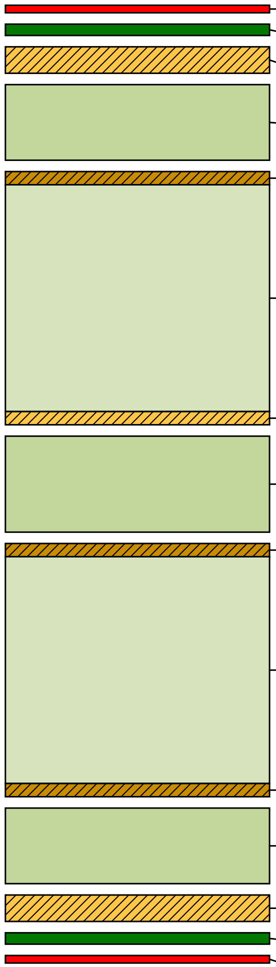


Realistic Isometric Drawings





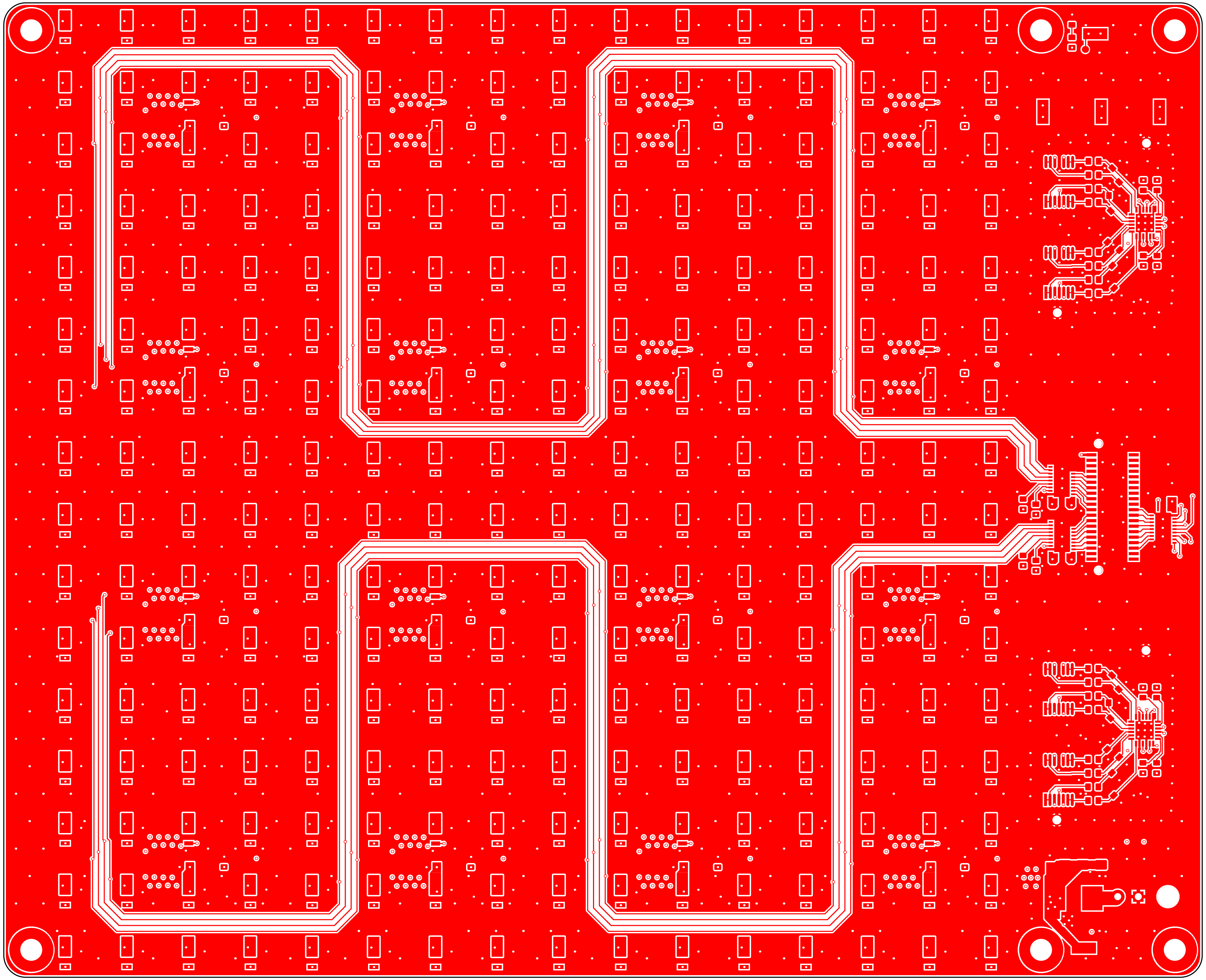
Stackup - Standard JLCPCB without Impedance Control



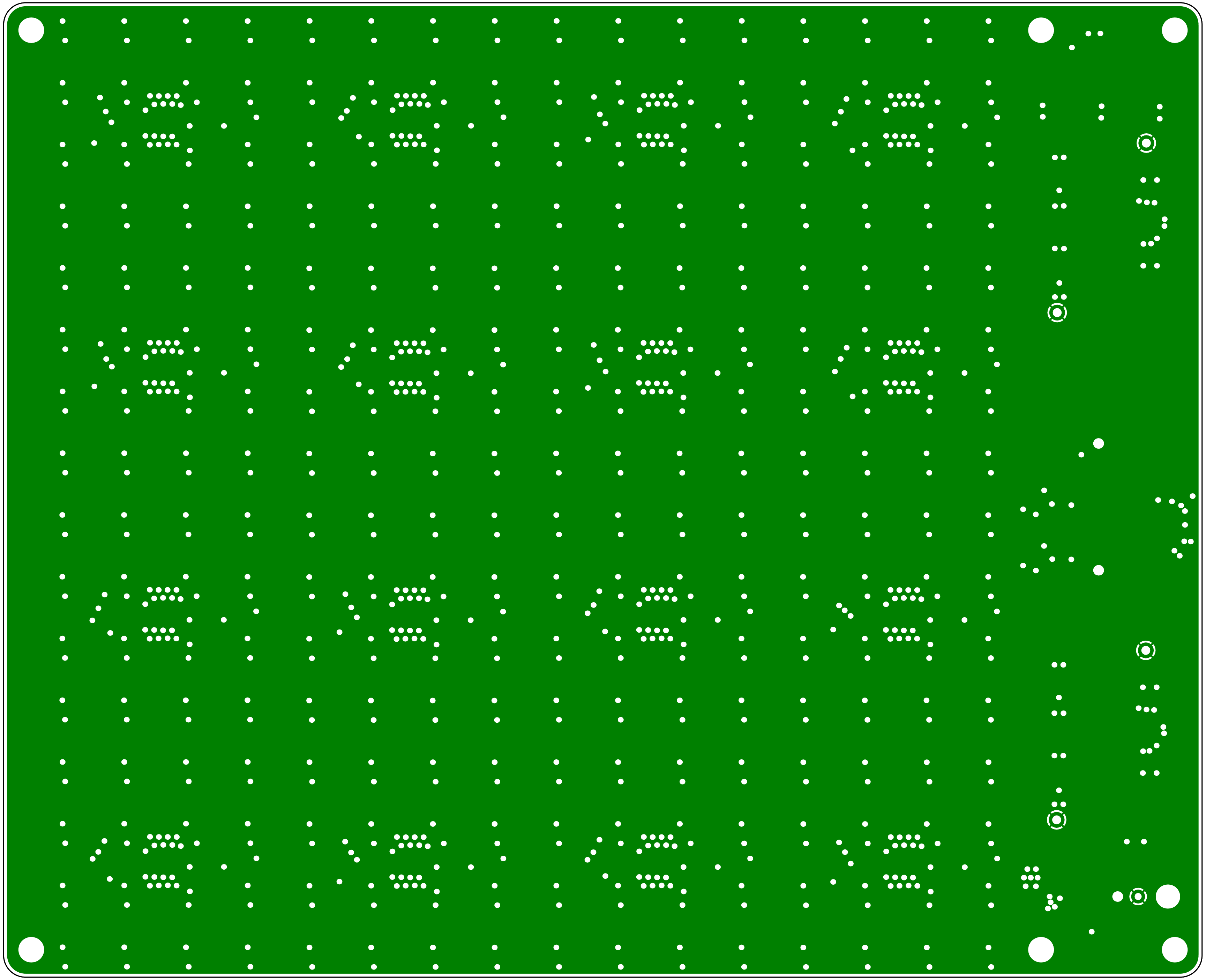
Material	Layer	Thickness	Dielectric Material	Type	Gerber
	Top Overlay			Legend	GTO
Surface Material	Top Mask	0.02mm	Solder Resist	Solder Mask	GTS
Copper	**L1 (SIG)**	**0.04mm**		**Signal**	**GTL**
Prepreg		*0.10mm*	*2313*	*Dielectric*	
Copper	**L2 (GND)**	**0.02mm**		**Internal Plane**	**GP1**
Core		*0.57mm*	*FR-4*	*Dielectric*	
Copper	**L3 (SIG)**	**0.02mm**		**Signal**	**G1**
Prepreg		*0.13mm*	*2116*	*Dielectric*	
Copper	**L4 (GND)**	**0.02mm**		**Internal Plane**	**GP2**
Core		*0.57mm*	*FR-4*	*Dielectric*	
Copper	**L5 (PWR)**	**0.02mm**		**Internal Plane**	**GP3**
Prepreg		*0.10mm*	*2313*	*Dielectric*	
Copper	**L6 (SIG)**	**0.04mm**		**Signal**	**GBL**
Surface Material	Bottom Mask	0.02mm	Solder Resist	Solder Mask	GBS
	Bottom Overlay			Legend	GBO

Total thickness: 1.63mm

L1 (SIG) Layer

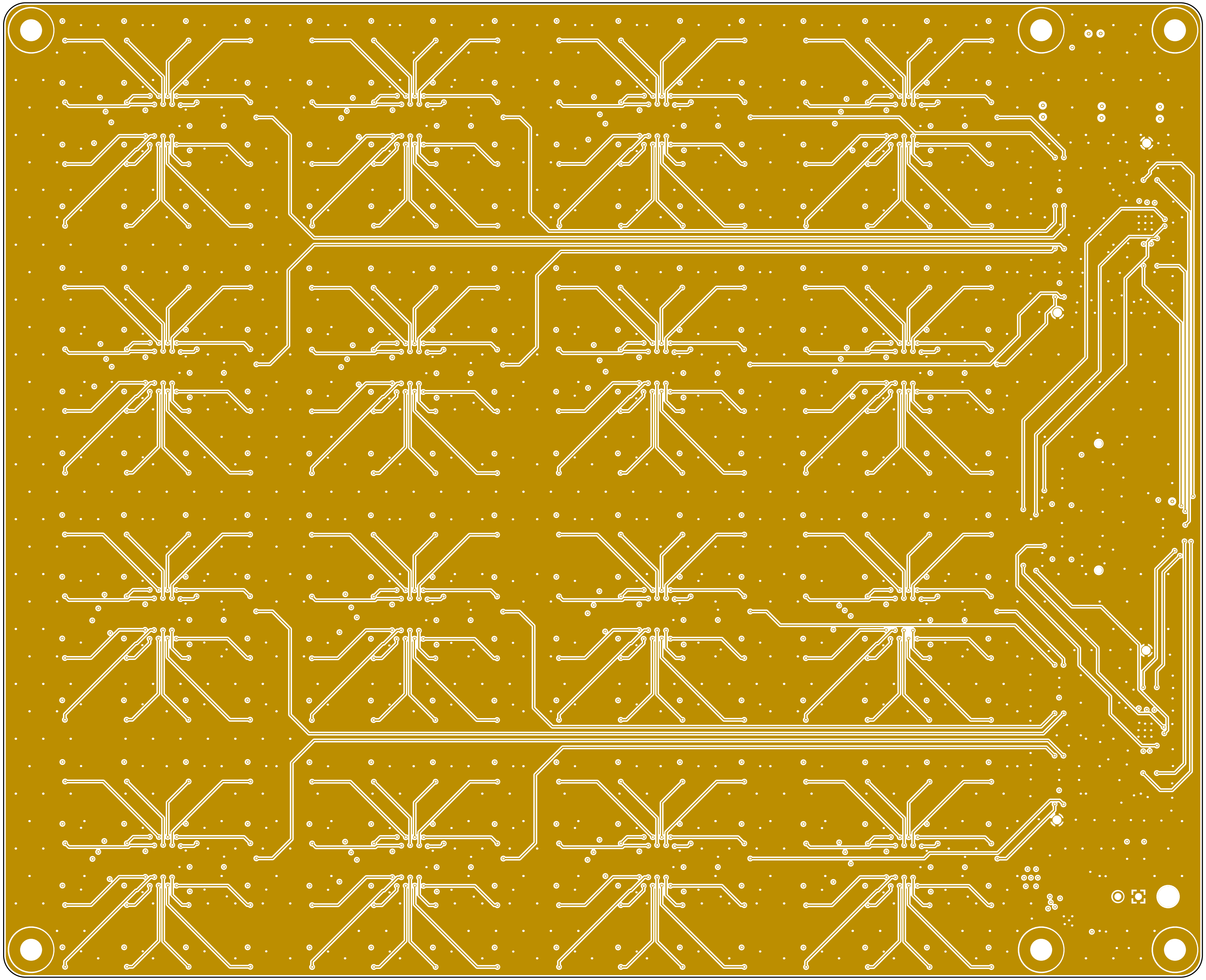


L2 (GND) Layer



A B C D E
1 2 3 4

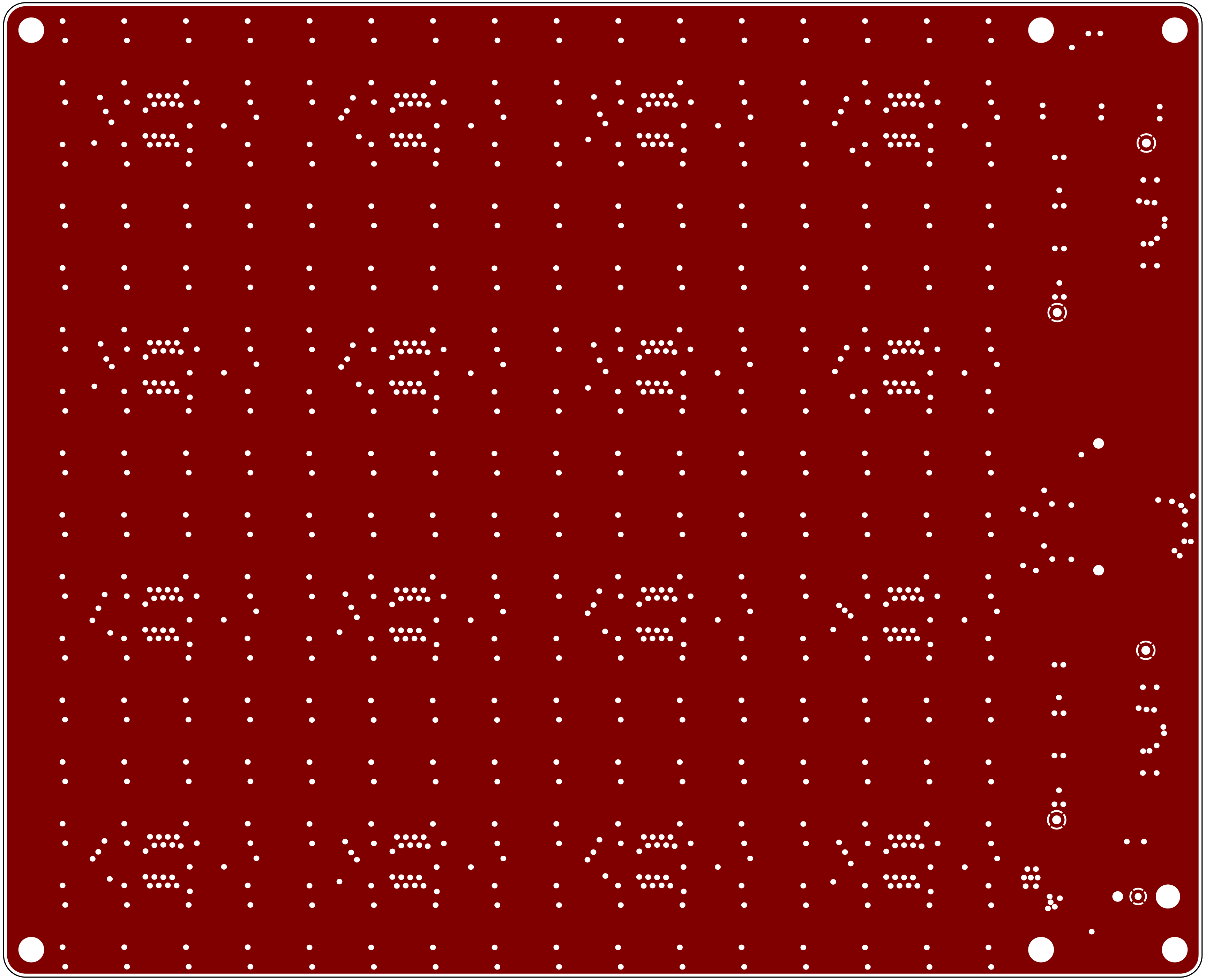
L3 (SIG) Layer



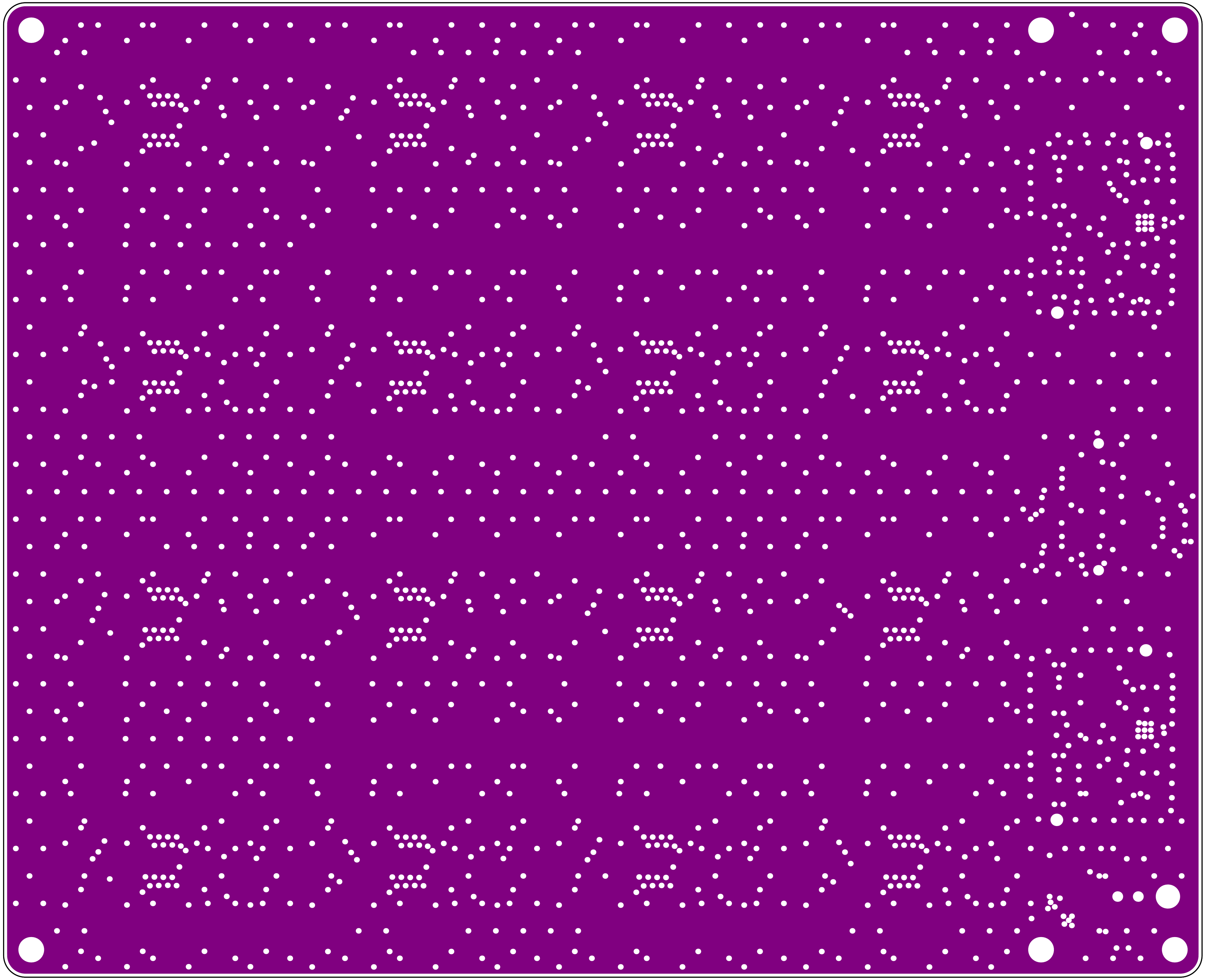
A B C D E

1 2 3 4

L4 (GND) Layer



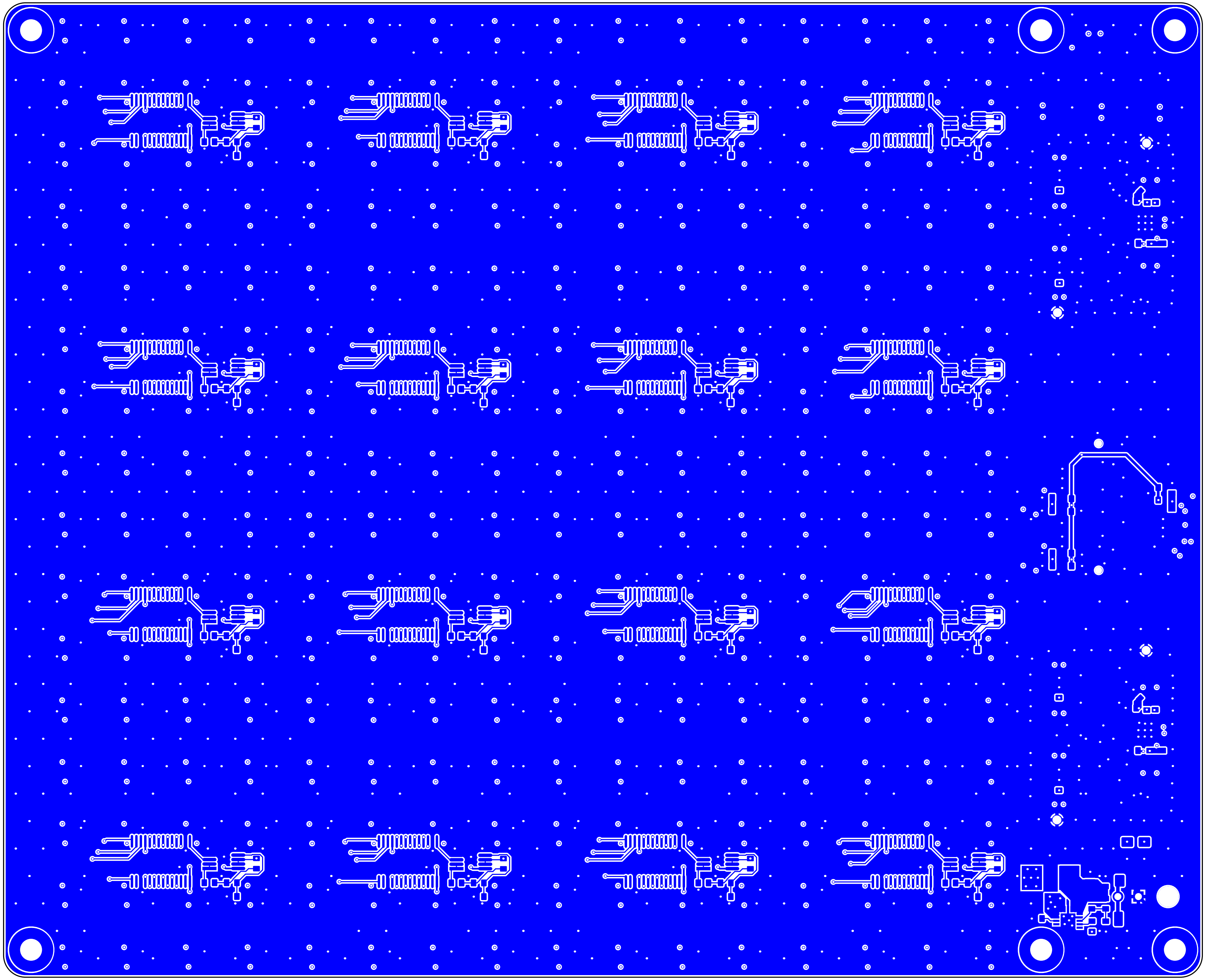
L5 (PWR) Layer



A B C D E

1 2 3 4

L6 (SIG) Layer



1 2 3 4

A B C D E