Progress on Metamaterial Absorbers

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1.1 Table of Contents

1.2 Short about my project

This project started off by Jon pitching to me to add a dogleg geometry to a hilbert absorber of triangular cross section as seen in figure 1.

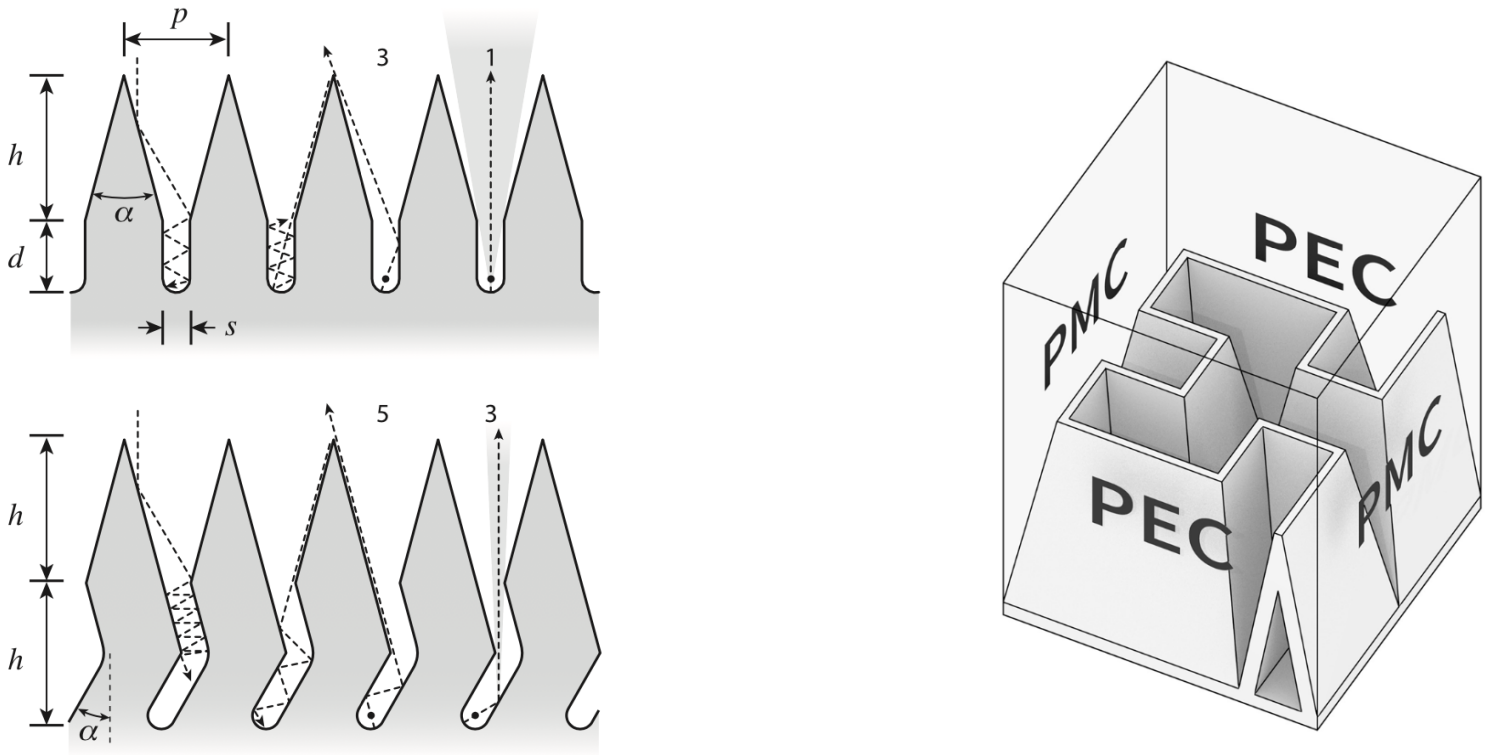


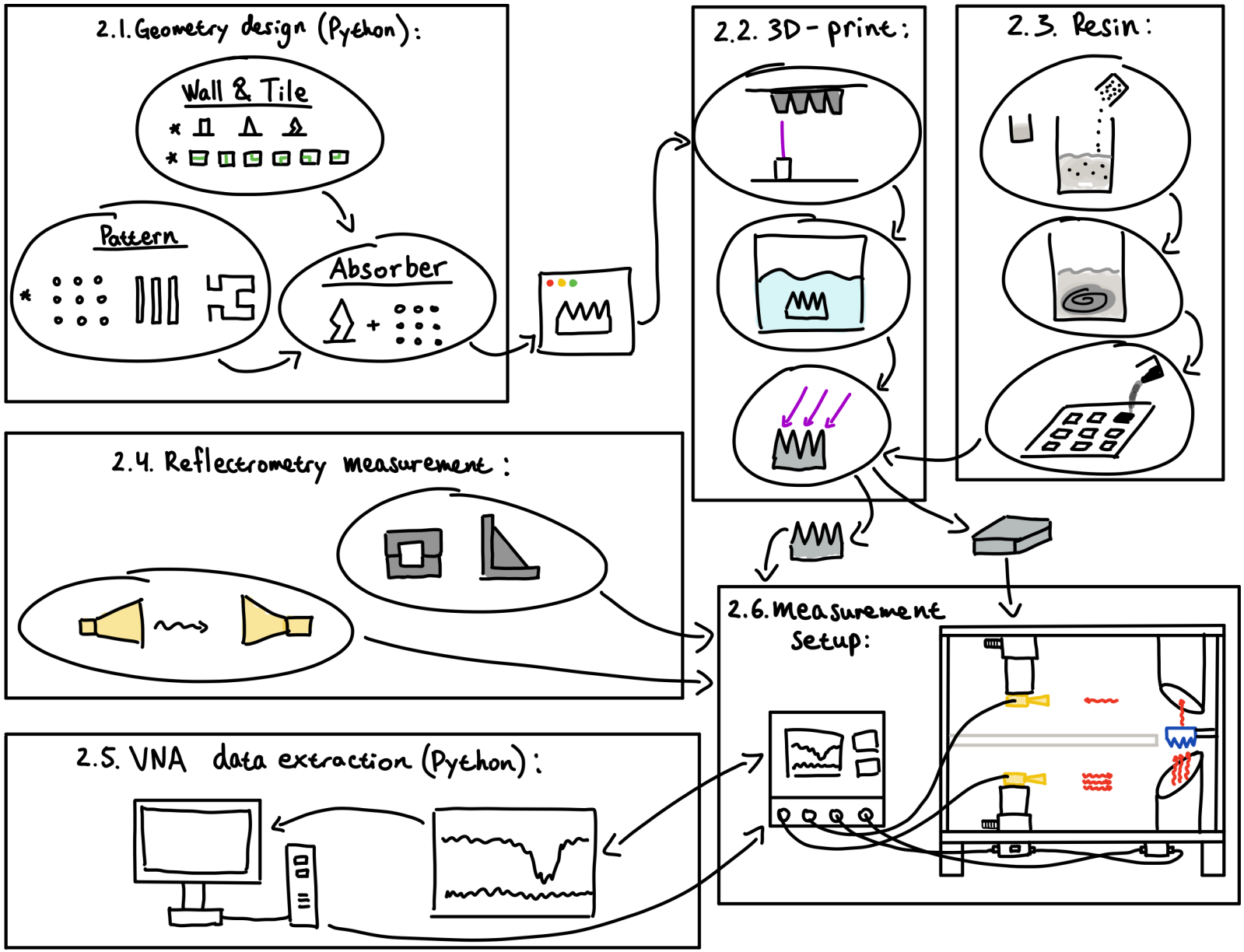
Figure 1: Top left: triangular cross section. Bottom left: dogleg cross section. Right: triangular shaped hilbert curve geometry. These are from Wollack and Petroff papers.[2][1]

1.2 Short about my project

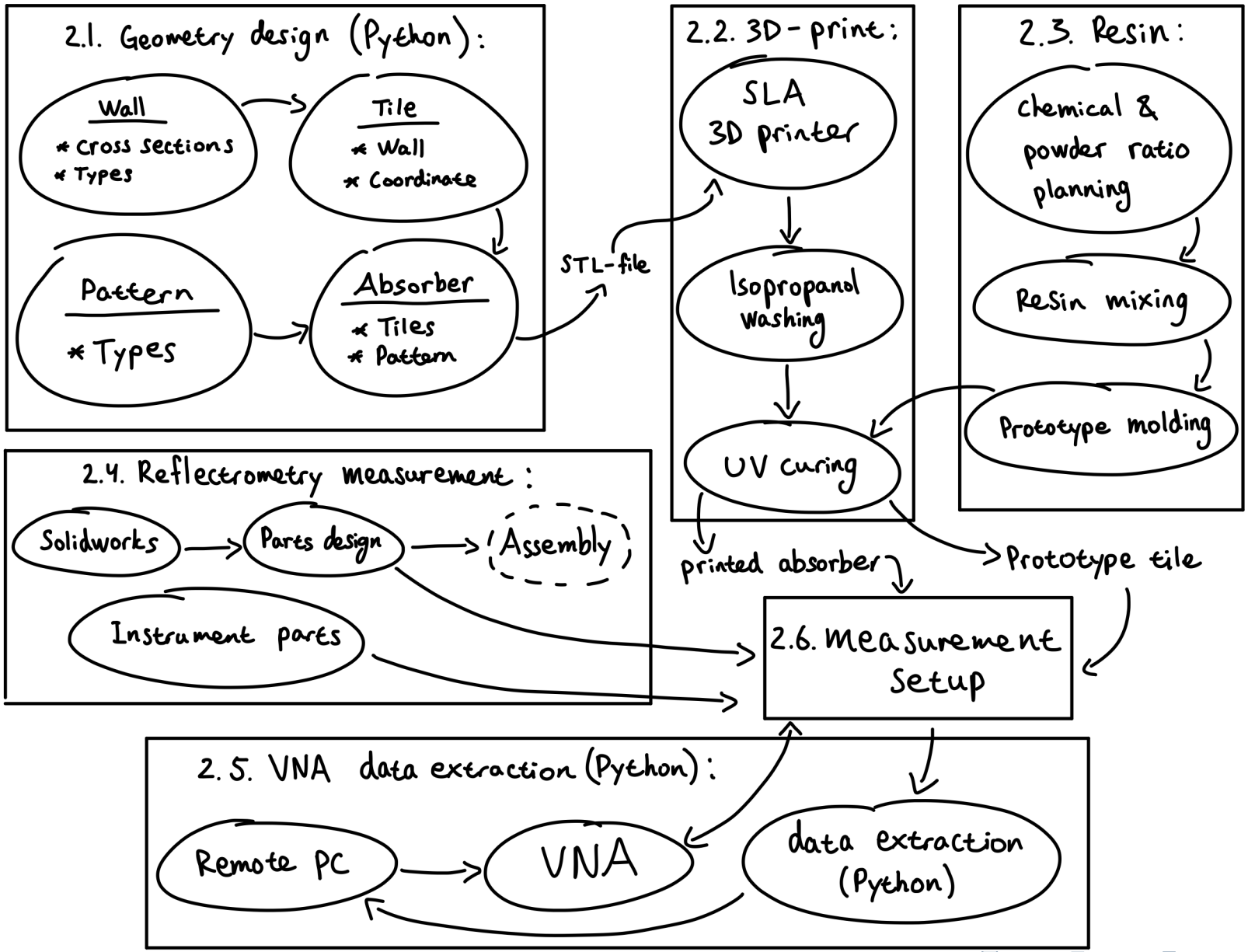
The summer project then further developed to several parts and went on for two months. It was about desining and testing different properties of new metamaterial absorbers. In the process, I got to discuss a lot with Gagan and Jon for the design and setup. The project includes:

1. Designing different geometries of absorbers in Python.
2. Learn and optimise SLA 3D printing, washing and curing.
3. Mixing different resins and test material properties.
4. Setting up static transmission system for measurements.
5. Learn to use VNA and write code to automate measurements remotely.

1.3 Overview and connections of project (in picture)



1.3 Overview and connections of project (in text)



2.1 Geometry design: Wall cross sections

The code consists of making different types of cross sections for walls, different wall tiles and patterns to be later combined into one absorber. We start by looking at different types of cross sections as seen in figure 2.

(a) Block

(b) Triangular

(c) Dogleg

Figure 2: Different types of cross sections designed with cadquery library in python code.

2.1 Geometry design: Dogleg geometry

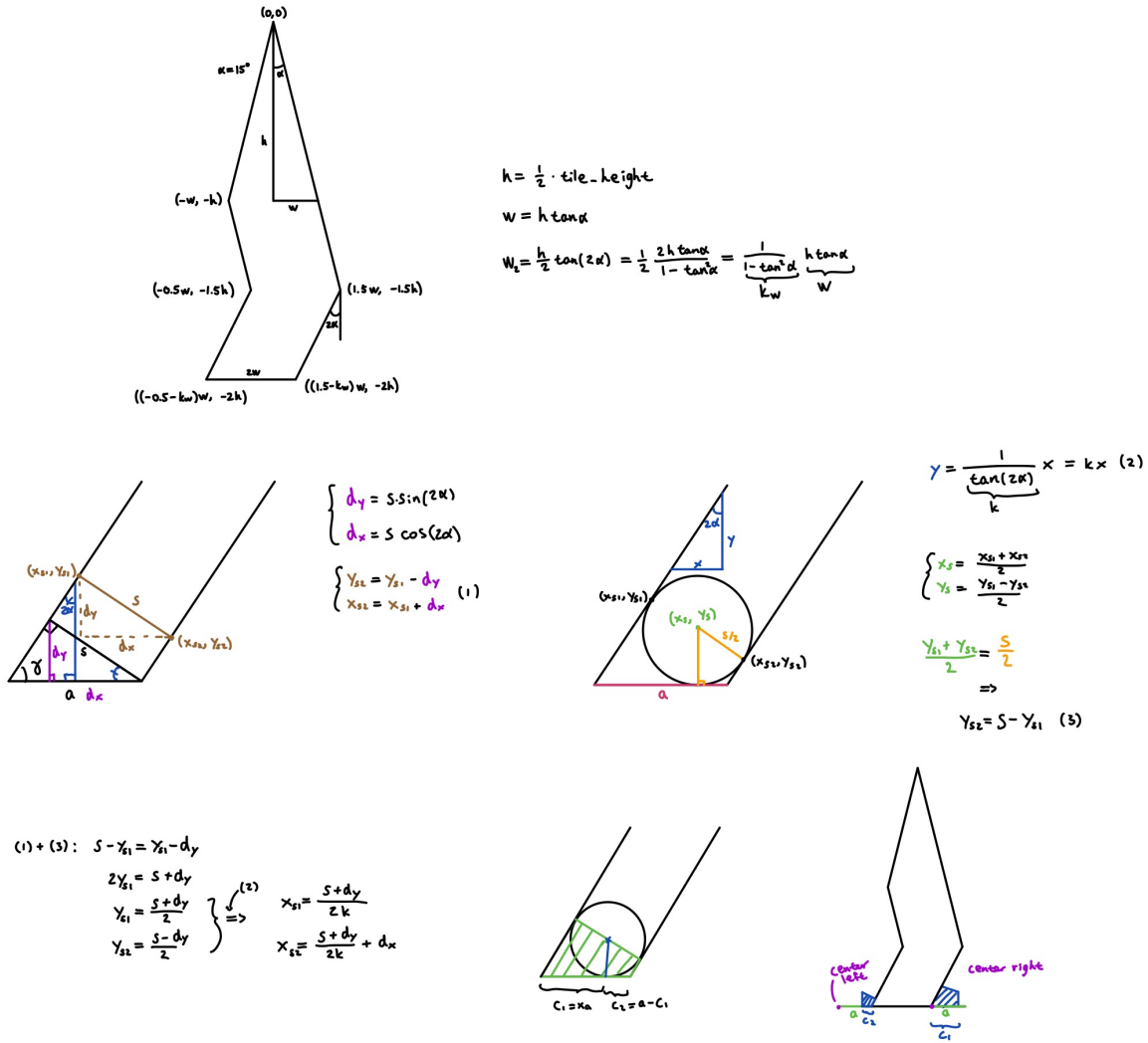


Figure 3: Image of dogleg geometry design which consists of the cross section and holes added to smooth out the transition to the tile floor.

2.1 Geometry design: Types of wall tiles

(a) Side

(b) Intersection

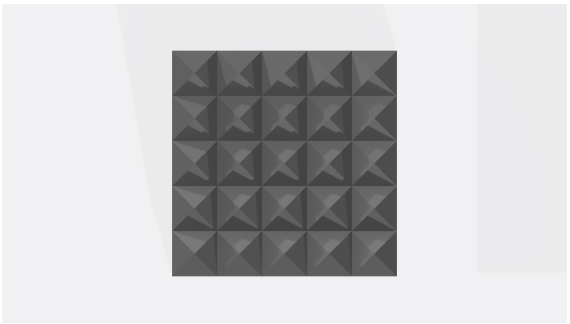
(c) Corner left up

(d) Corner right down

Figure 4: Example of different types of walls used to make different absorbers.

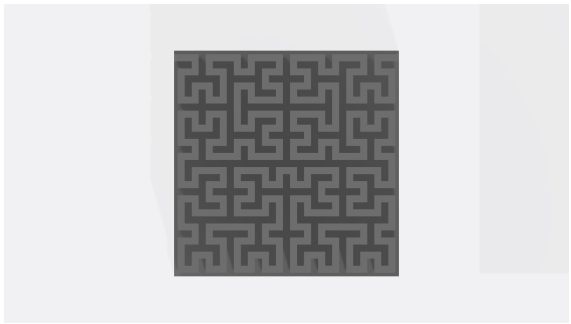
2.1 Geometry design: Patterns

We now look at different patterns in figure 5. Hilbert curves are generated quite easily with L-systems.



(a) Dots

(b) Rows



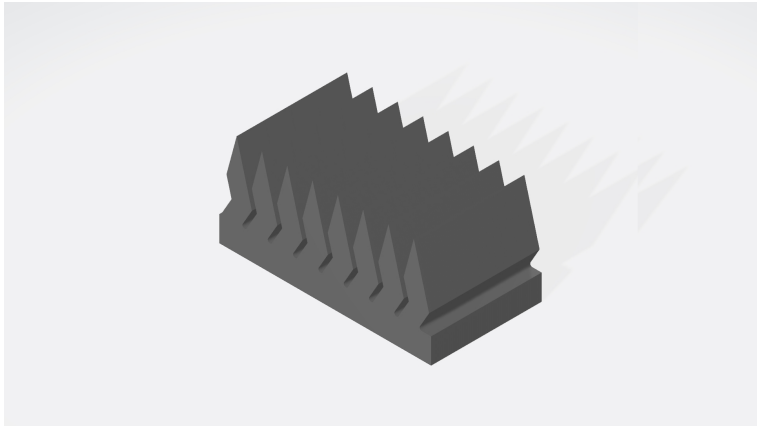
(c) Hilbert

Figure 5: Different types of patterns designed with cadquery library in python code.

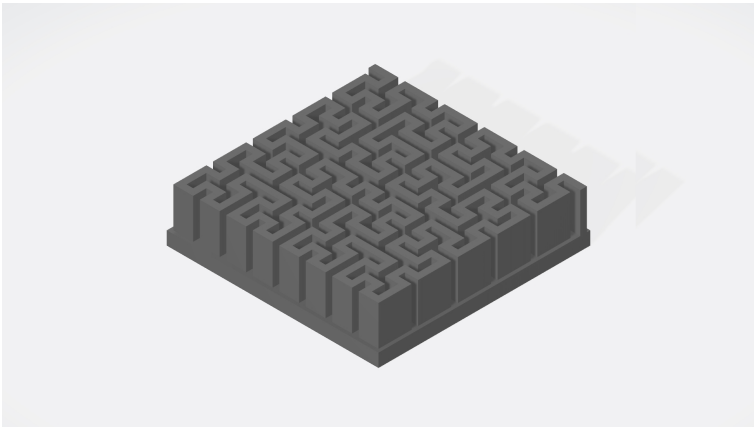
2.1 Geometry design: Absorbers

The finished absorber designs examples looks like these:

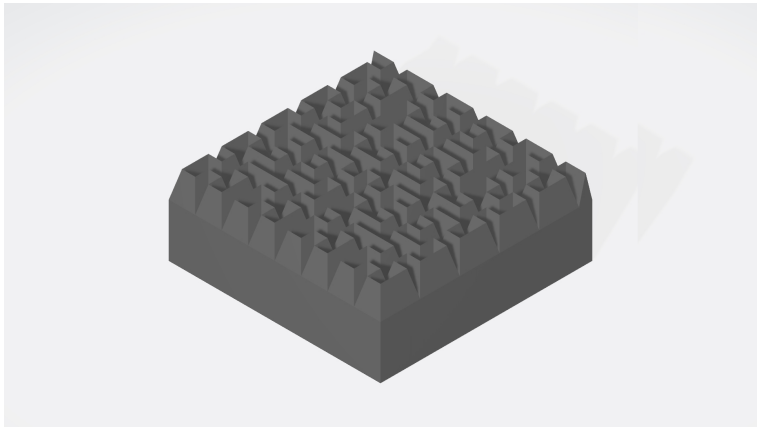
(a) Triangle dots



(b) Dogleg rows



(c) Block hilbert curve

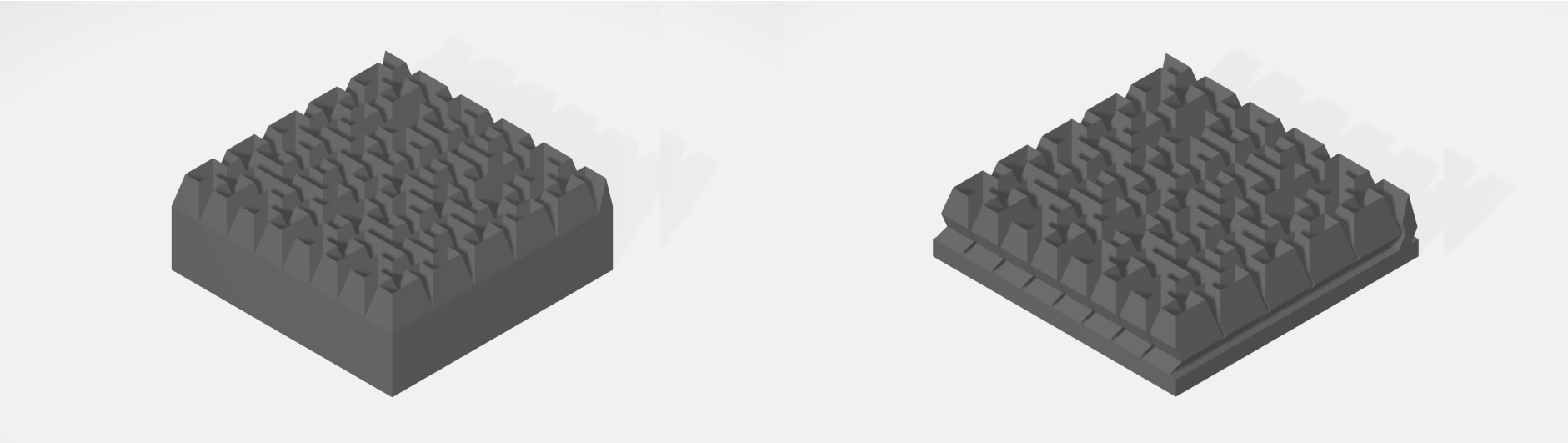


(d) Triangular hilbert curve

Figure 6: Absorbers make by by different combinations of walls and patterns.

2.1 Geometry design: Dogleg hilbert curve absorber

Finally! The hilbert curve absorber of dogleg cross section was made!



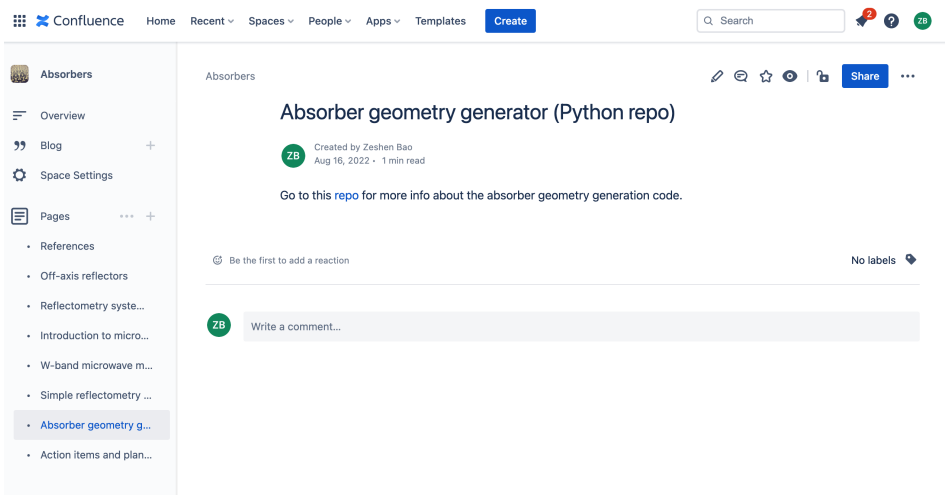
(a) Triangular hilbert

(b) Dogleg hilbert

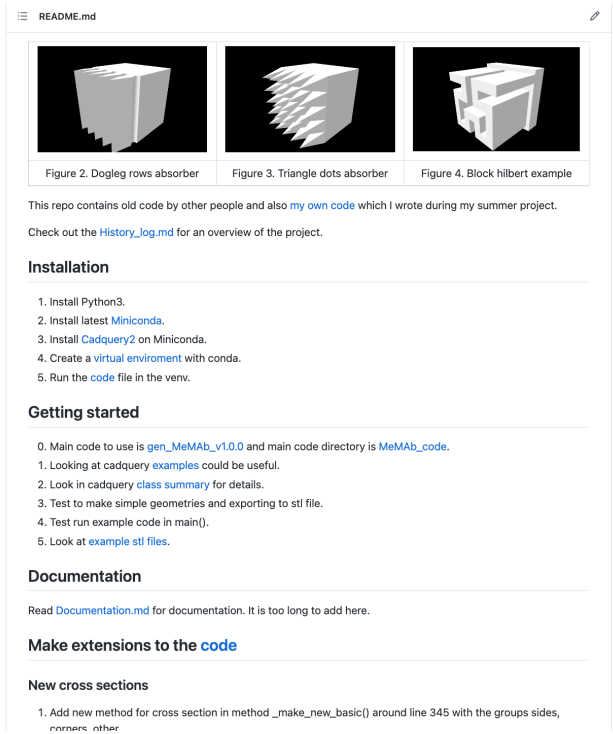
Figure 7: Comparison of triangular and dogleg hilbert curve absorbers.

2.1 Geometry design: Repo

I've made a repo with guides, documentation and other files for the code you can check out. There is a link in Confluence or check my github at https://github.com/zeshenbao



(a) Confluence page



(b) Github repo

Figure 8: Overview of Confluence and my github repository.

2.1 Geometry design: History log and documentation

673 lines (514 sloc) | 22.5 KB

15/06-22

Plan:

1. Study the print.
2. Finish writing the geometry file, add dog_leg later.
3. Start making Hilbert curve with blocks, continue to pyramid which requires corner sections, etc.

Did:

1. We studies the print and looks like the print is very dependent on the film quality and condition. We should change to a new film for optimal prints. The metal plating seemed fine.

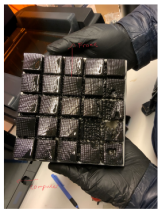


fig. printed lots of absorbers to fit the printing plate to check deformations.

2. Finished the geometry class file and also written in functions depending on use, class is more difficult to use.
3. Written the code to generate hilbert curves with L-system and drawed it with turtle. I'll continue with integrate it with walls.

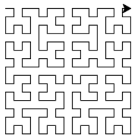


fig. generated hilbert curve with turtle graphics.

To do:

(a) Project history log

356 lines (269 sloc) | 10.1 KB

Documentation

gen_MeMAb v1.0.0

16 august 2022, Zeshen Bao

Classes

class Absorber

```
class Absorber():
    """Implements a absorber with different patterns and wall segments.
    """
```

method init

```
def __init__(self, wall, pattern):
        """Creates an absorber object with input wall tiles and pattern.
        The start result is a empty cq.Workplane object in XY plane.

        Parameters
        ----------

        wall: wall object
            Wall object includes different types of tiles.

        pattern: pattern object
            Pattern object has a specific pattern.

        result: cq.Workplane object
            Cadquery workplane is empty by creation and generated by build() method.
        """
```

method build

```
def build(self):
        """Builds the absorber with the blueprint instance variable stored in pattern object."""
```

method export

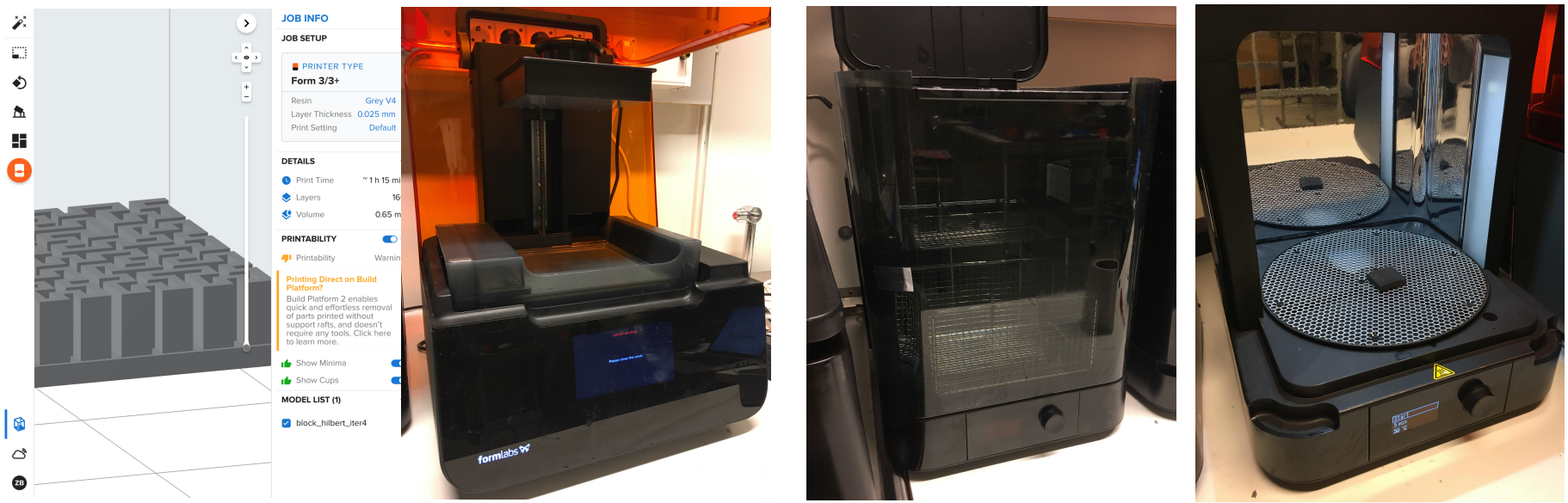
```
def export(self):
        """Export the genereted cq.Workplane object stored as self.result to a stl file
```

(b) Documentation of code

Figure 9: Overview of history log and documentation.

2.2 3D-printing: Process

Making absorber consists of pre-printing, printing, washing and curing.



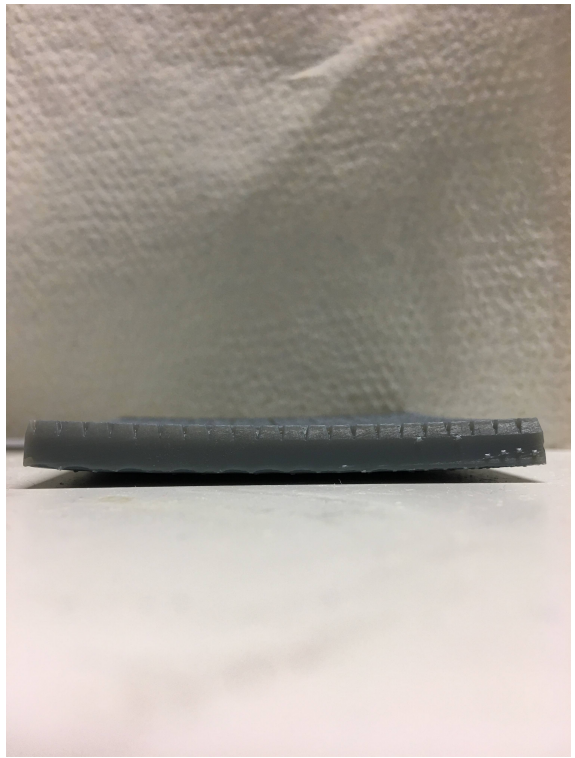
(a) Setup in software (b) SLA 3D printing (c) Washing (d) Curing

Figure 10: Process of 3D printing.

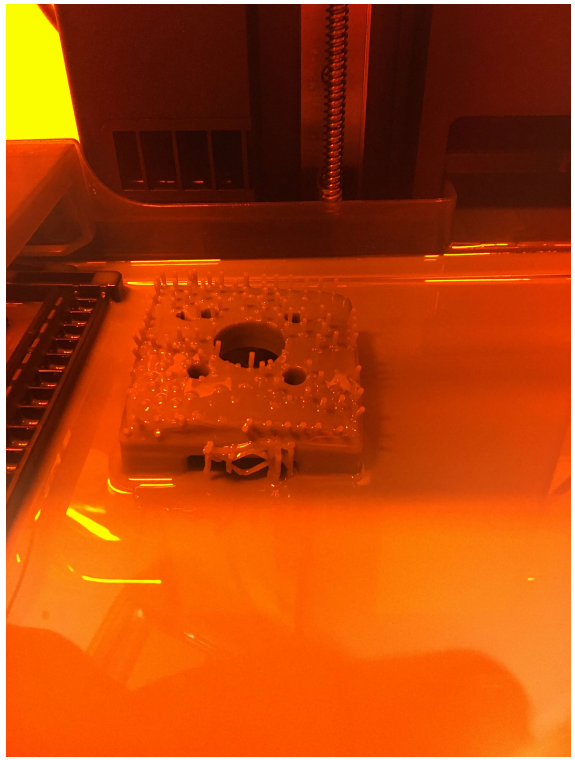
2.2 3D-printing: Errors, failures and testing

During the project, we tried to minimize different printing failures and deformations from heat and wash by changing settings.

(a) Printer film dents



(b) Absorber deformation

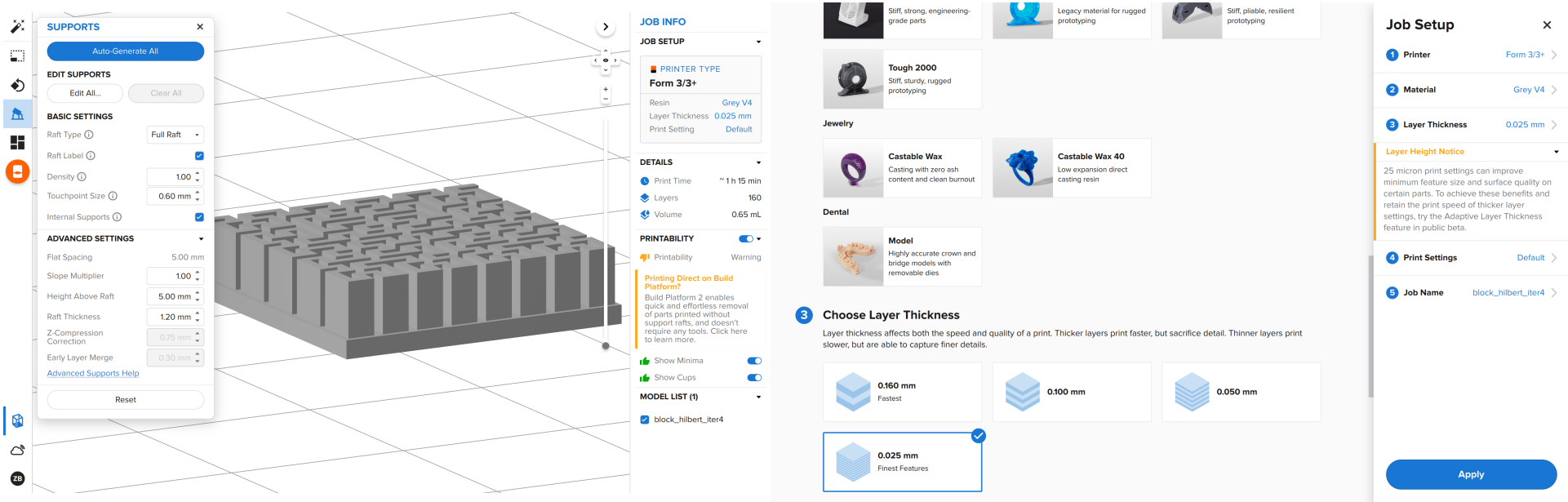


(c) Printing support failure

Figure 11: Examples of errors and failures during printing.

2.2 3D-printing: Preform settings

We tested different print settings in formlabs to avoid support failure, deformations and more. Other measures are changing wash and cure time, print thicker foundations or other solutions.



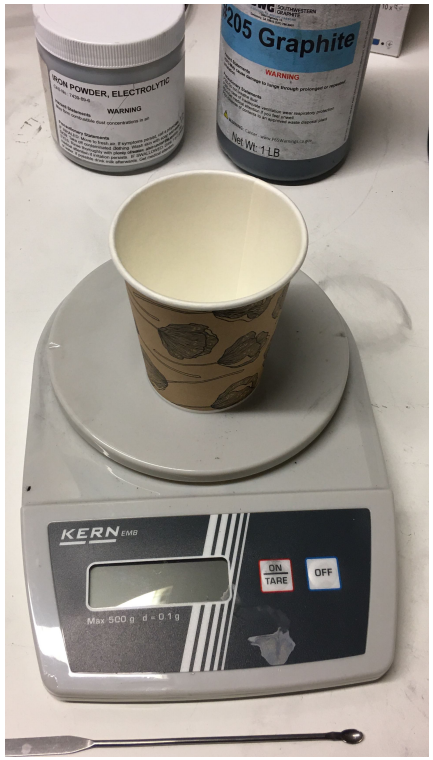
(a) Support settings

(b) Material and layer settings

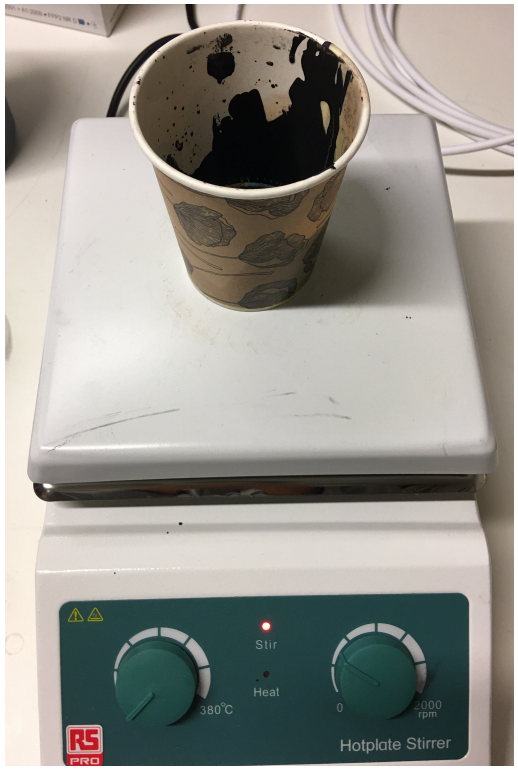
Figure 12: Preform settings to vary for better quality prints.

2.3 Resin development

We also tried to develop new resins which got into many problems.



(a) Adding different additives to resin



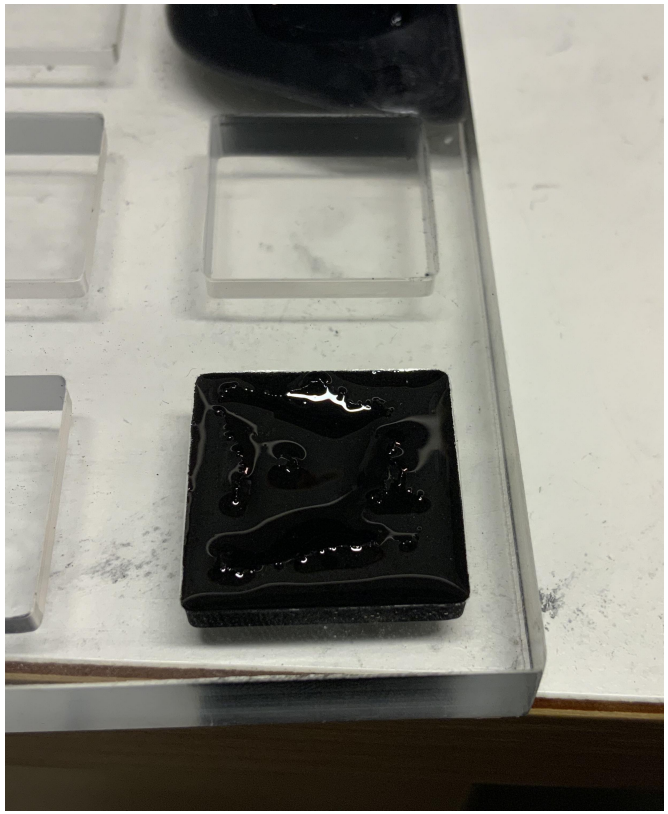
(b) Mixing new resin

Figure 13: Mixing process of resin developement.

2.3 Resin development: Errors

We got into problems like mixing high viscosity fluids, mixing magnetic iron powder, curing thick layers, manufacturing with low resin volumes.

(a) High viscusity and magnatic iron powder mixing failure.

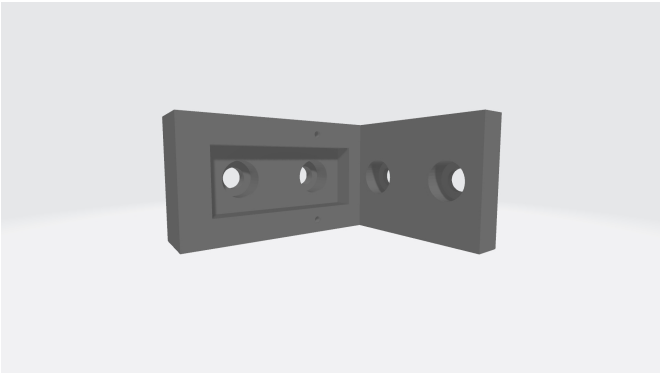


(b) Unable to cure higher thickness of resin with curing machine.

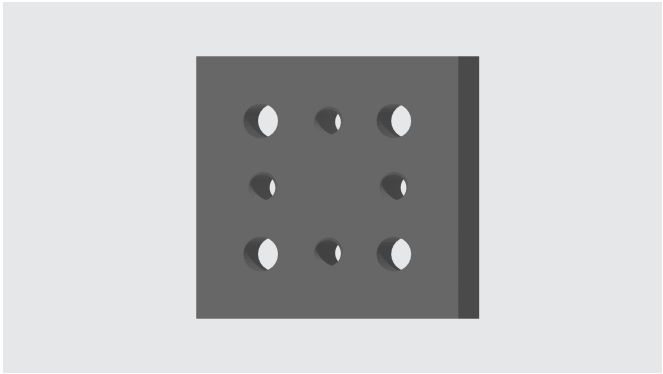
Figure 14: Example of resin failures.

2.4 Transmission measurement setup

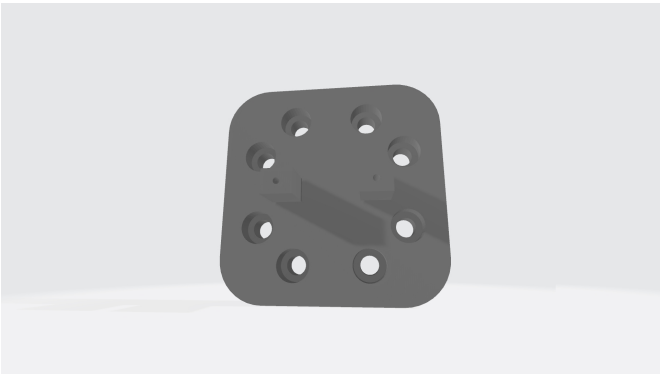
We could not make accurate measurements of resin characteristics with a multimeter so we tried to setup our transmission measurement system.



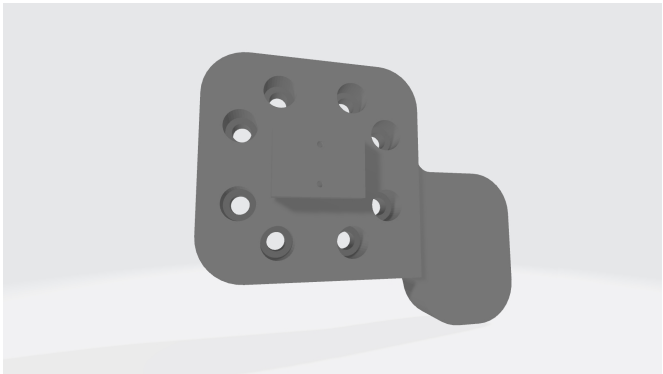
(a)



(b)



(c)

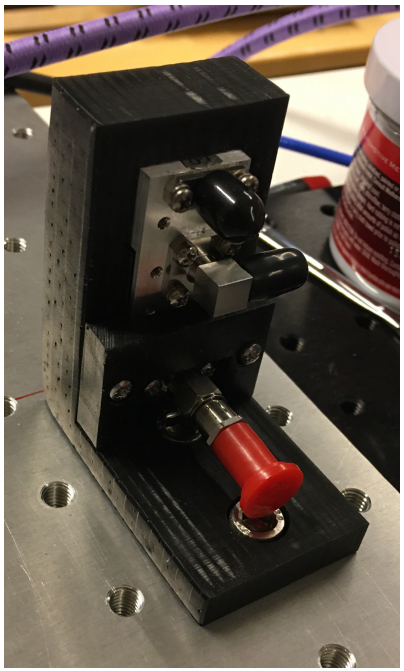


(d)

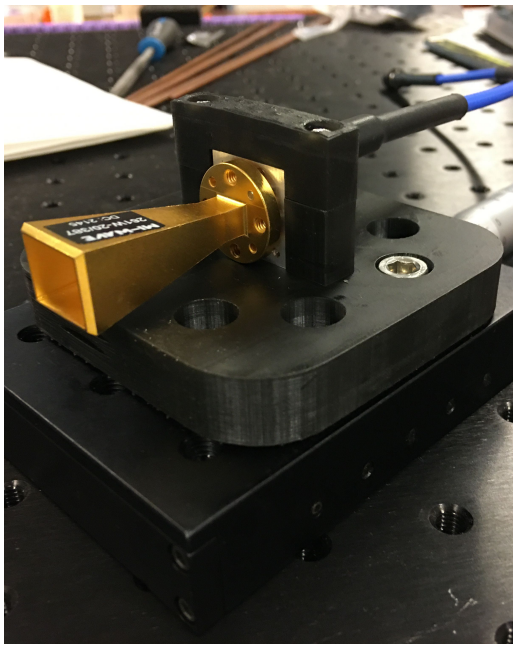
Figure 15: Solidwoks parts to 3D print for fastening instruments.

2.4 Transmission measurement setup: Printed parts

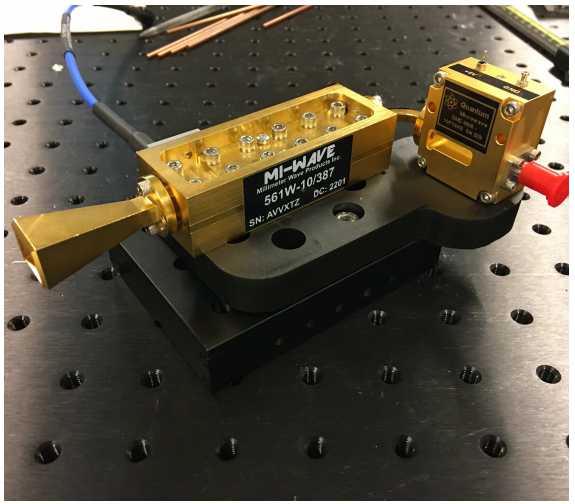
Printed Solidwork parts are shown in the figure below.



(a) Modmd4a



(b) W-band receiver

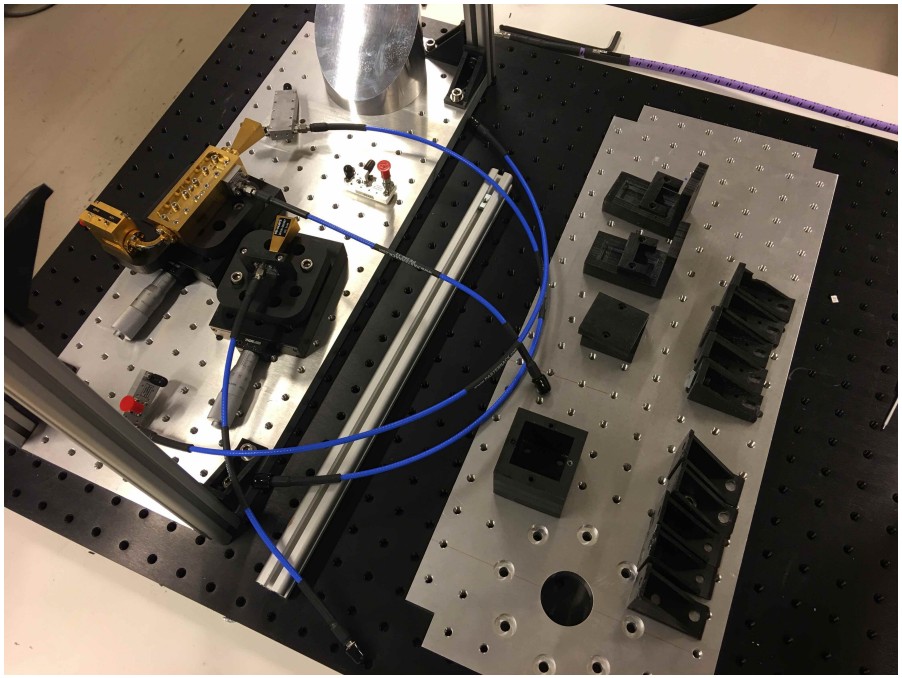


(c) W-band transmitter

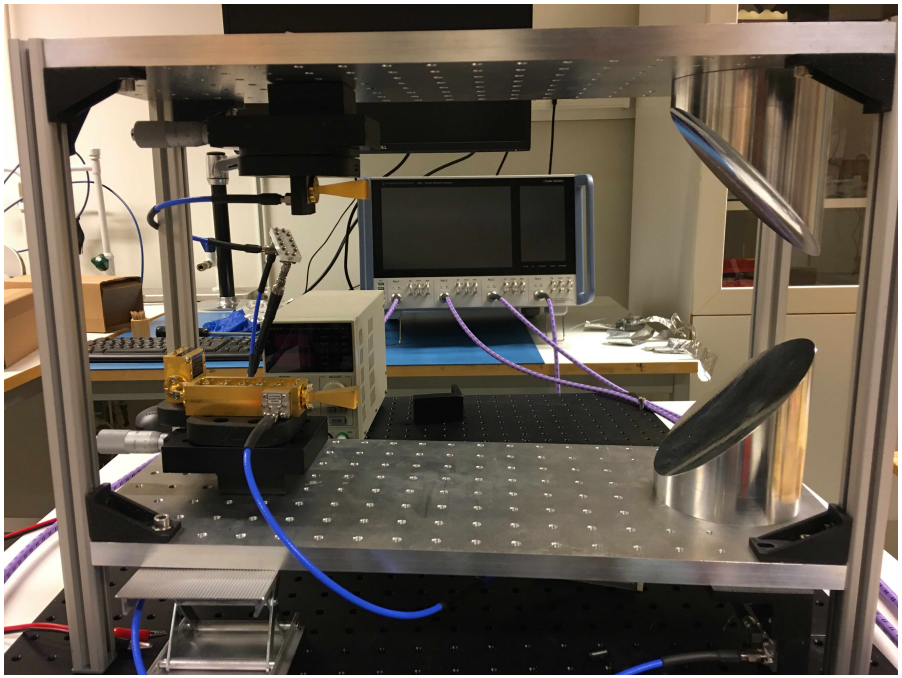
Figure 16: printed parts for instruments.

2.4 Transmission measurement setup: Assembled

We assembled the transmission measurement system setup and where ready to make measurements.



(a) Before assembly

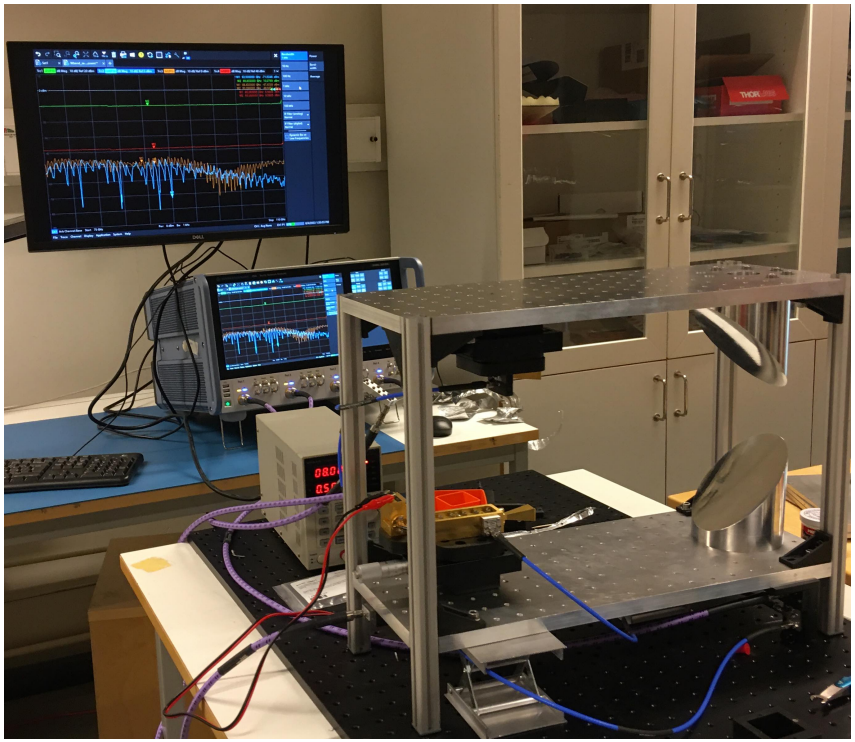


(b) After assembly

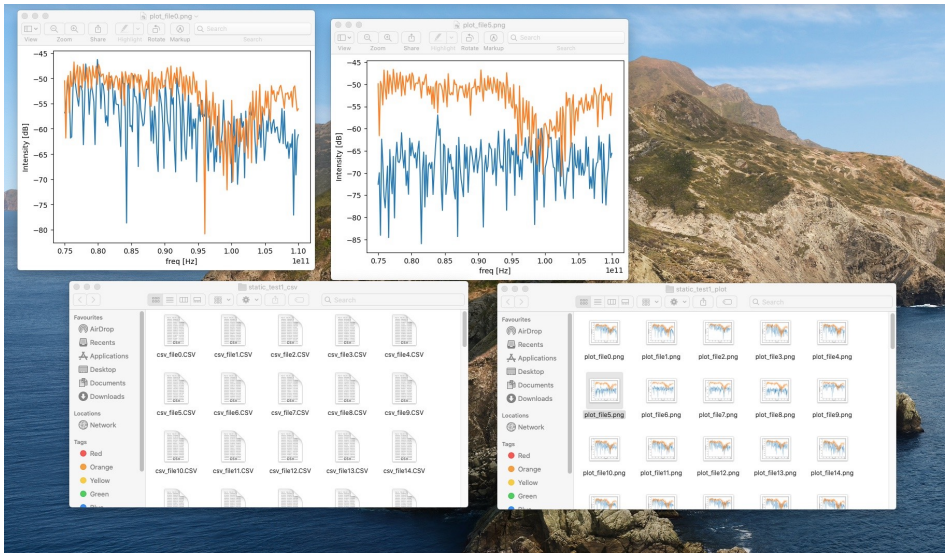
Figure 17: Transmission measurement system.

2.5 VNA data extraction

For measurements, we connected our transmission system setup to a VNA. I wrote a python script to remote control the VNA with its preset measurement setup to the Mac to extract data automatically. The script consists of automatically syncing, reading sweeps and then plots data with matplotlib.



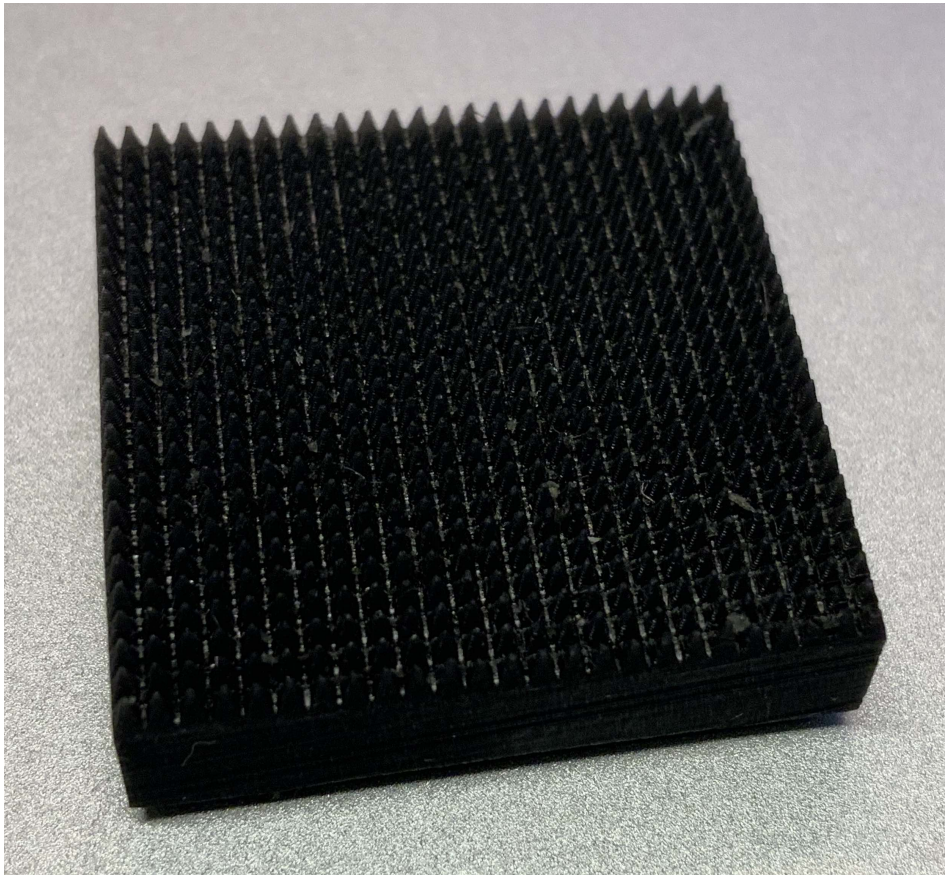
(a) VNA measuring transmission.



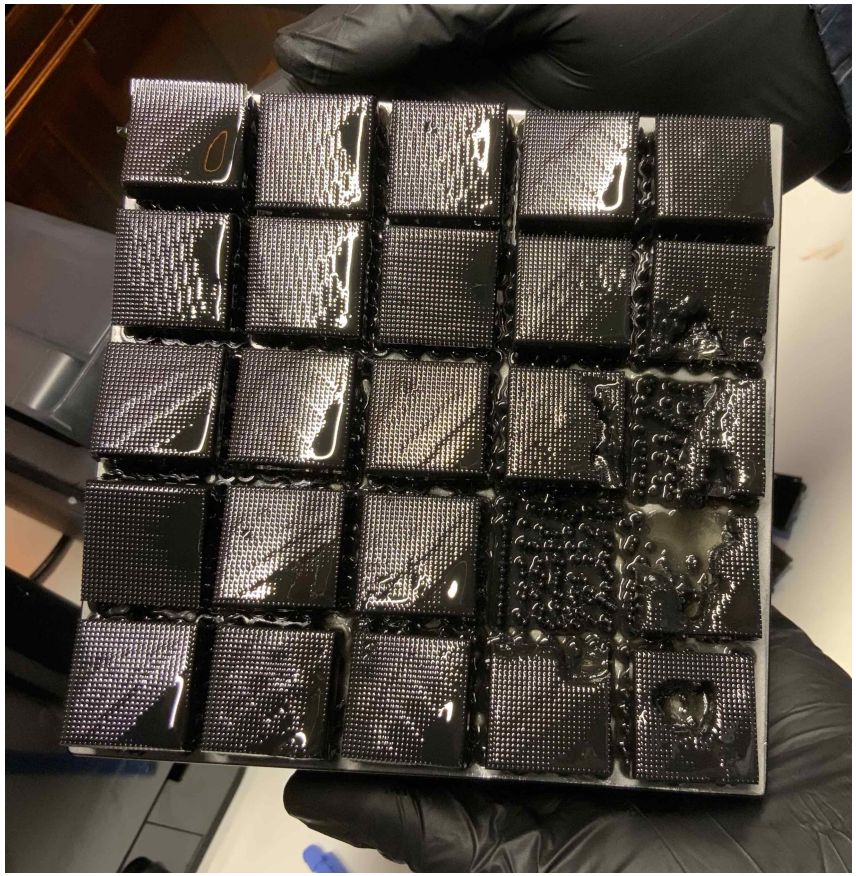
(b) Mac reading and extracting sweeps.

Figure 18: Measurement setup and remote controlling.

3. Absorber prints showcase: Standard absorbers



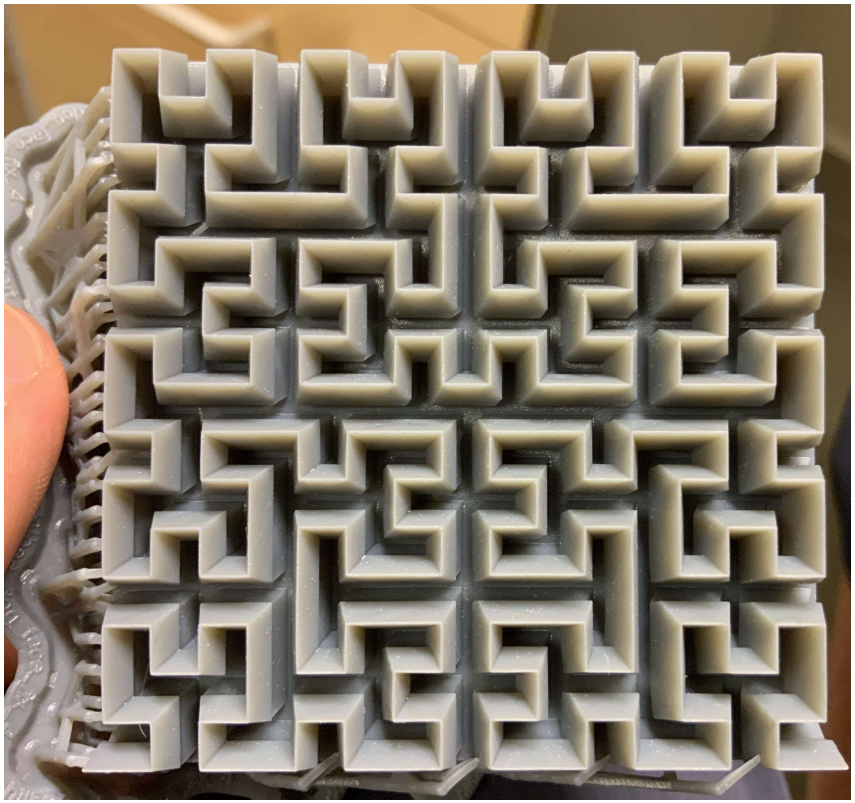
(a) Tiny standard pyramid absorber



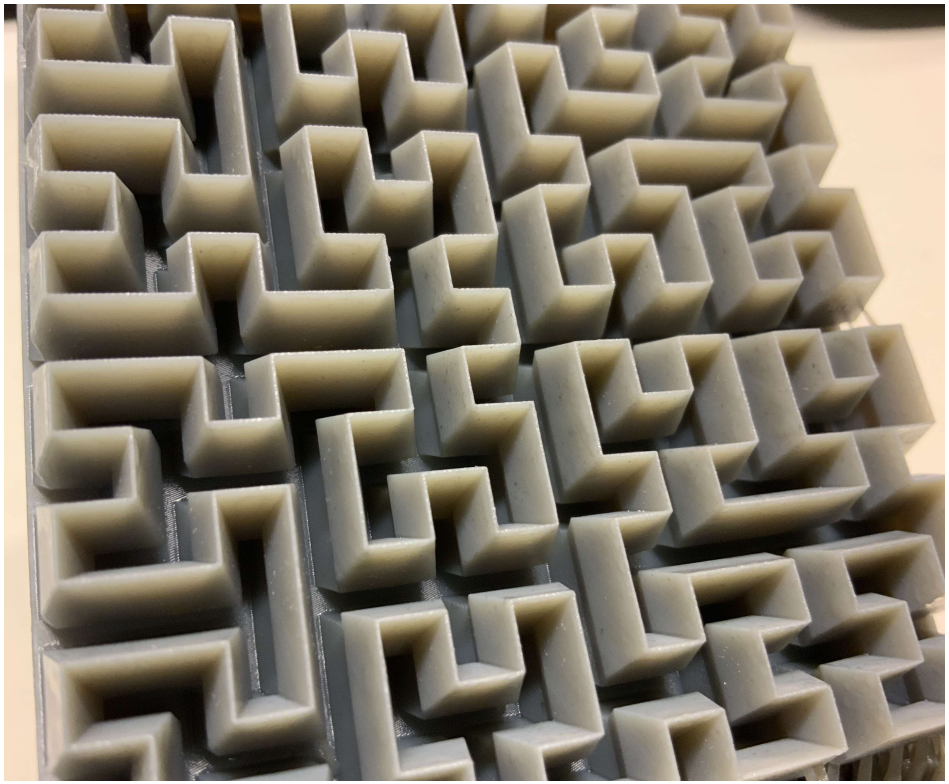
(b) Many pyramid absorbers

Figure 19: Printing standard absorbers.

3. Absorber prints showcase: First dogleg hilbert absorber



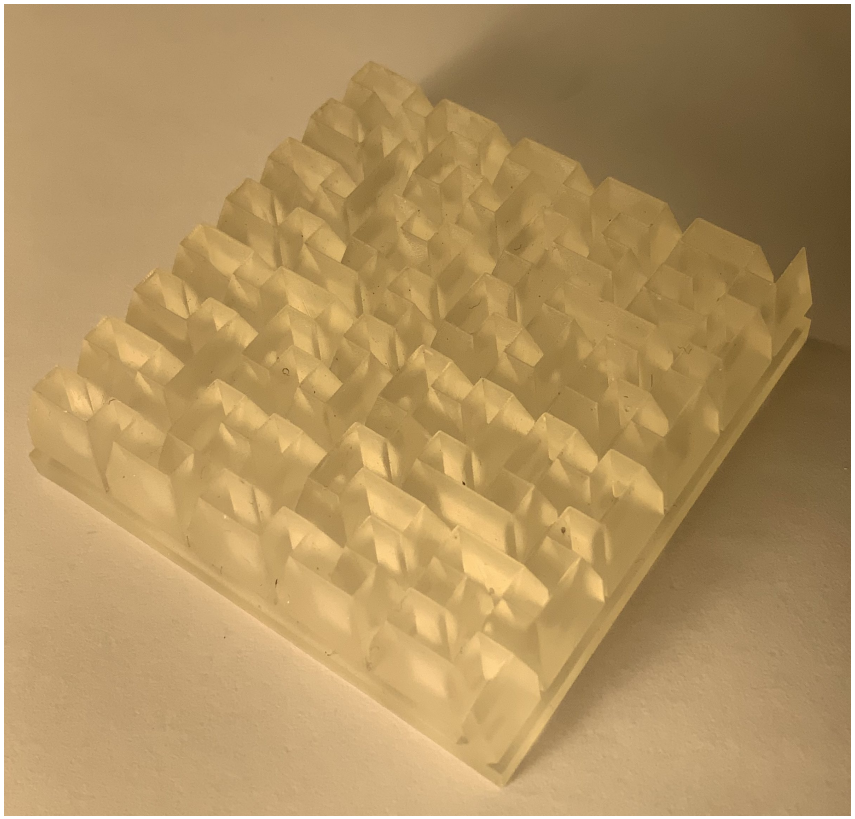
(a) View from above



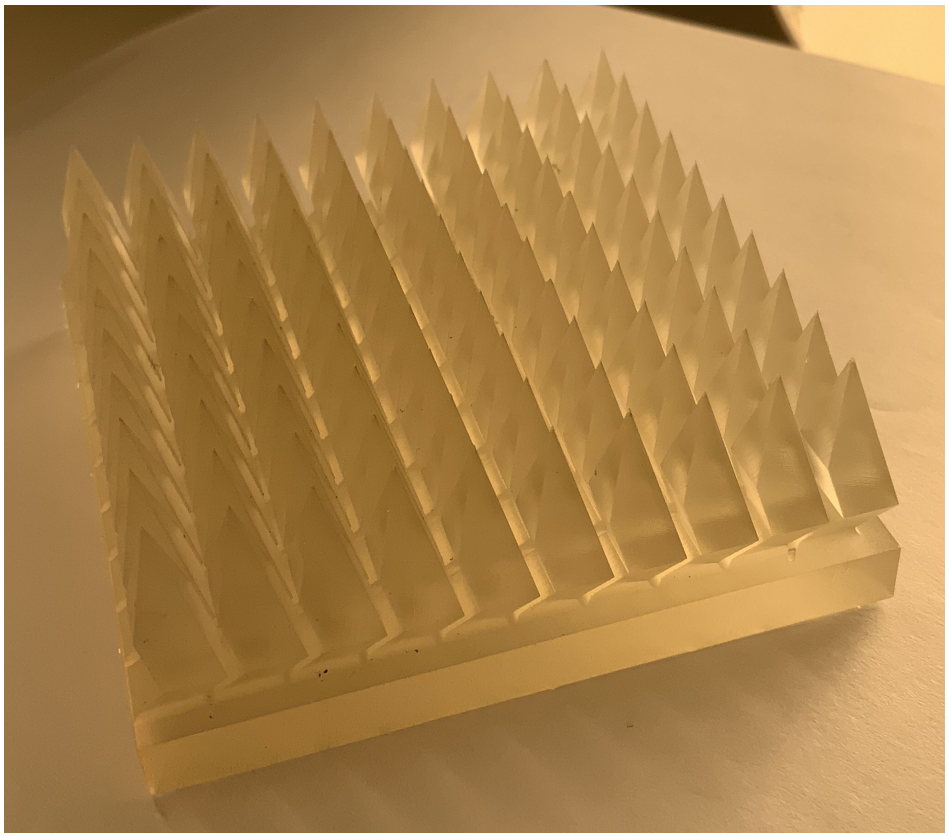
(b) View from front

Figure 20: First prototype of dogleg hilbert absorber.

3. Absorber prints showcase: Improved dogleg absorbers



(a) Improved dogleg hilbert absorber



(b) Improved hilbert dot absorber

Figure 21: Improved variants of dogleg absorbers.

4. Further developments

1. Make measurements of resin characteristics.
2. Manufacture absorber with our own resin and make new measurements.
3. Fix measurement system alignment issues.
4. Isolate setup from disturbances and noise.
5. Add extensions to the code with new pattern and cross sections.
6. Upgrade VNA remote control code and make nicer plots.
7. Setup reflectometry system to measure reflection and absorbsion instead of transmission.
8. Much much more.

5. References

Matthew Petroff, John Appel, Karwan Rostem, Charles L. Bennett, Joseph Eimer, Tobias Marriage, Joshua Ramirez, and Edward J. Wollack.
A 3d-printed broadband millimeter wave absorber.
Review of Scientific Instruments, 90(2):024701, 2019.

E. J. Wollack, R. E. Kinzer, and S. A. Rinehart.
A cryogenic infrared calibration target.
Review of Scientific Instruments, 85(4):044707, apr 2014.

End slide

I'm really glad that I could work with the Cmbeam team this summer and I want to thank you all!

Thanks for listening!