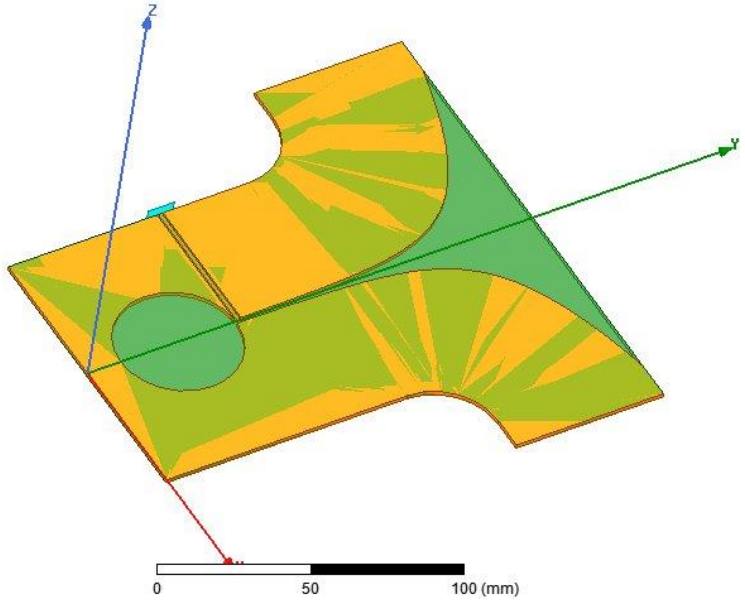
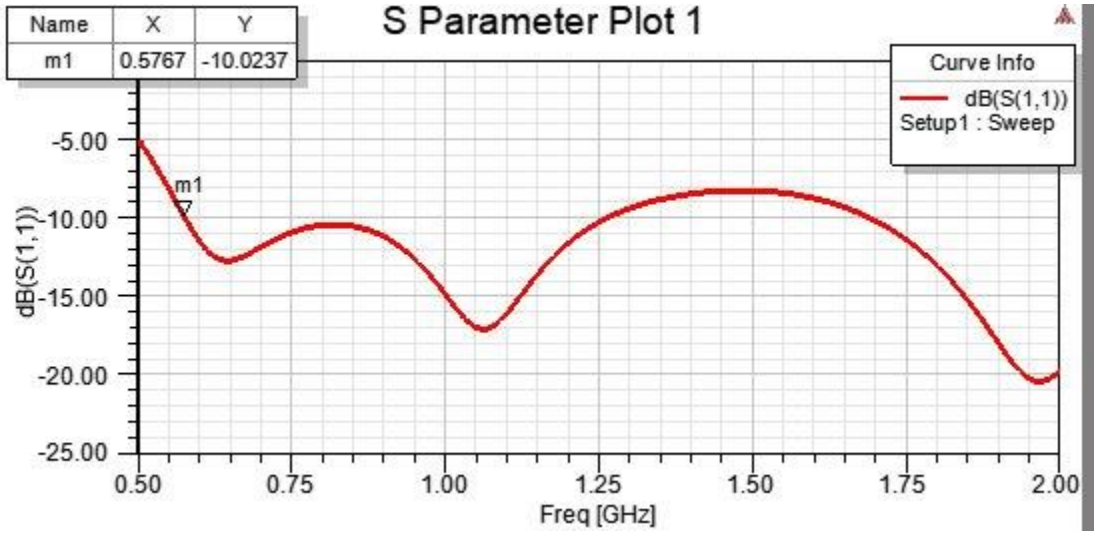
Measure Permittivity of Non-flat Soil Using Machine Learning

Antenna

Vivaldi antenna is chosen as it is wideband, directive, easy to feed and cheap to build.
Total size: 170mm x 172 mm

The antenna is operating from about 0.6 GHz to more than 2 GHz. The frequency range for the experiment is chosen as from 0.6 GHz to 1 GHz as the permittivity of the soil is approximately constant in this range (to be verified with Alex)



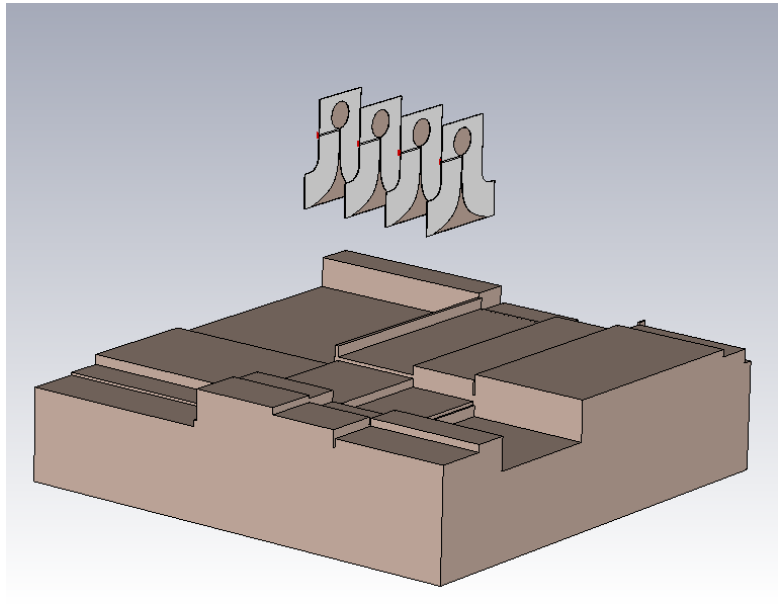


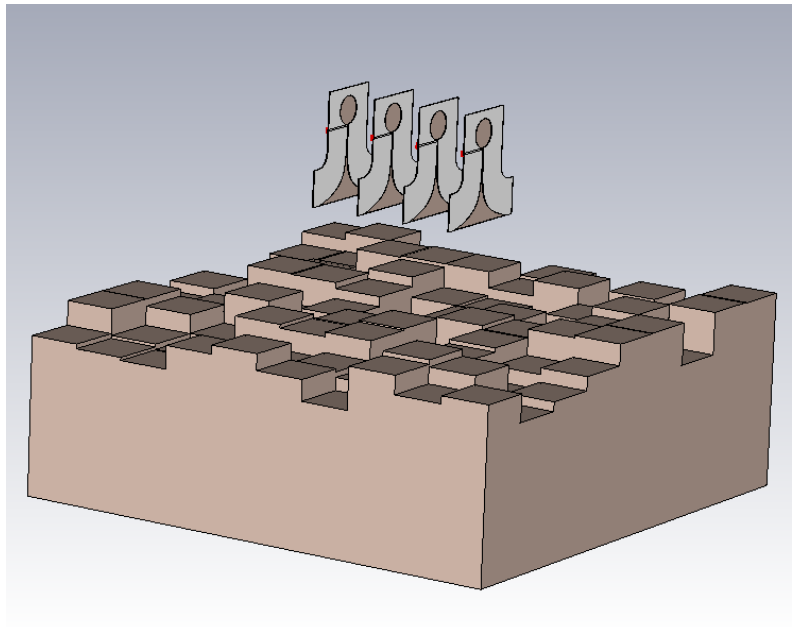
Simulation set up

- 4 antennas are used
- Soils are simulated with random permittivity (ranging from 3 to 40) and random surface.

(Note that 3 corresponds to 0% of water and 78 corresponds to 100% of water)

- The distance between the antenna and the soil also varies





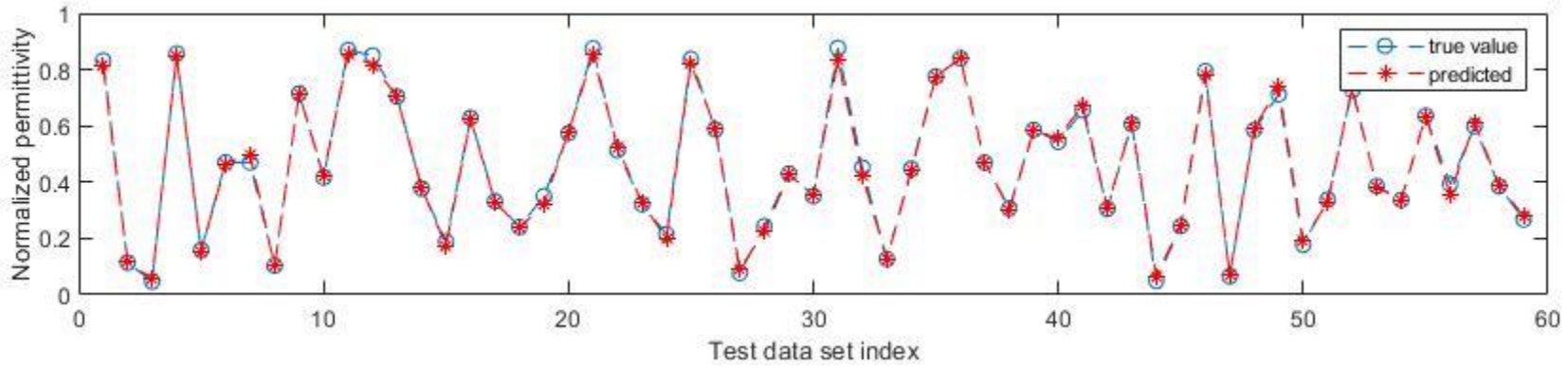
Machine Learning

- Large amount of data is collected with random soil shape and permittivity (about 1000 samples).
- These data are used to train the neural network to predict the correct permittivity of the soil
- The optimized parameters of neural network are then verified with different set of data

Machine Learning

- The results show a great potential. Neural network can predict the permittivity very accurately.
- This type of results can be obtained **with only two antennas.**

Nevertheless, **the more antennas, the more information we can obtained** and the more chance we can deal with more complicated situations such as the soil is not homogeneous.



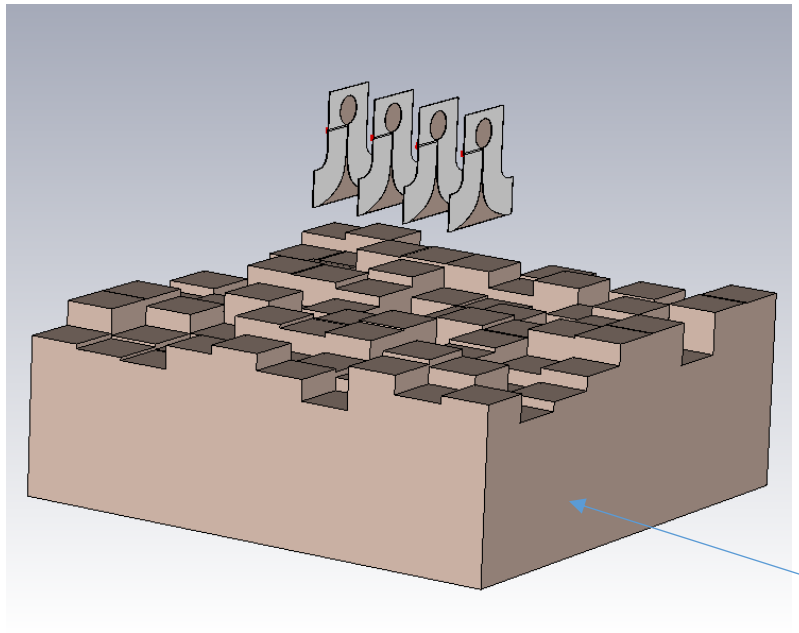
Obviously there are still several challenges to discuss and address such as calibration.

Important Points to Discuss

- Is there any metal, i.e. target, in the soil?
- How homogeneous is the soil?
- Is there any magnetic material in the soil?
- Do we have a floor, e.g. a water bed, for the soil?

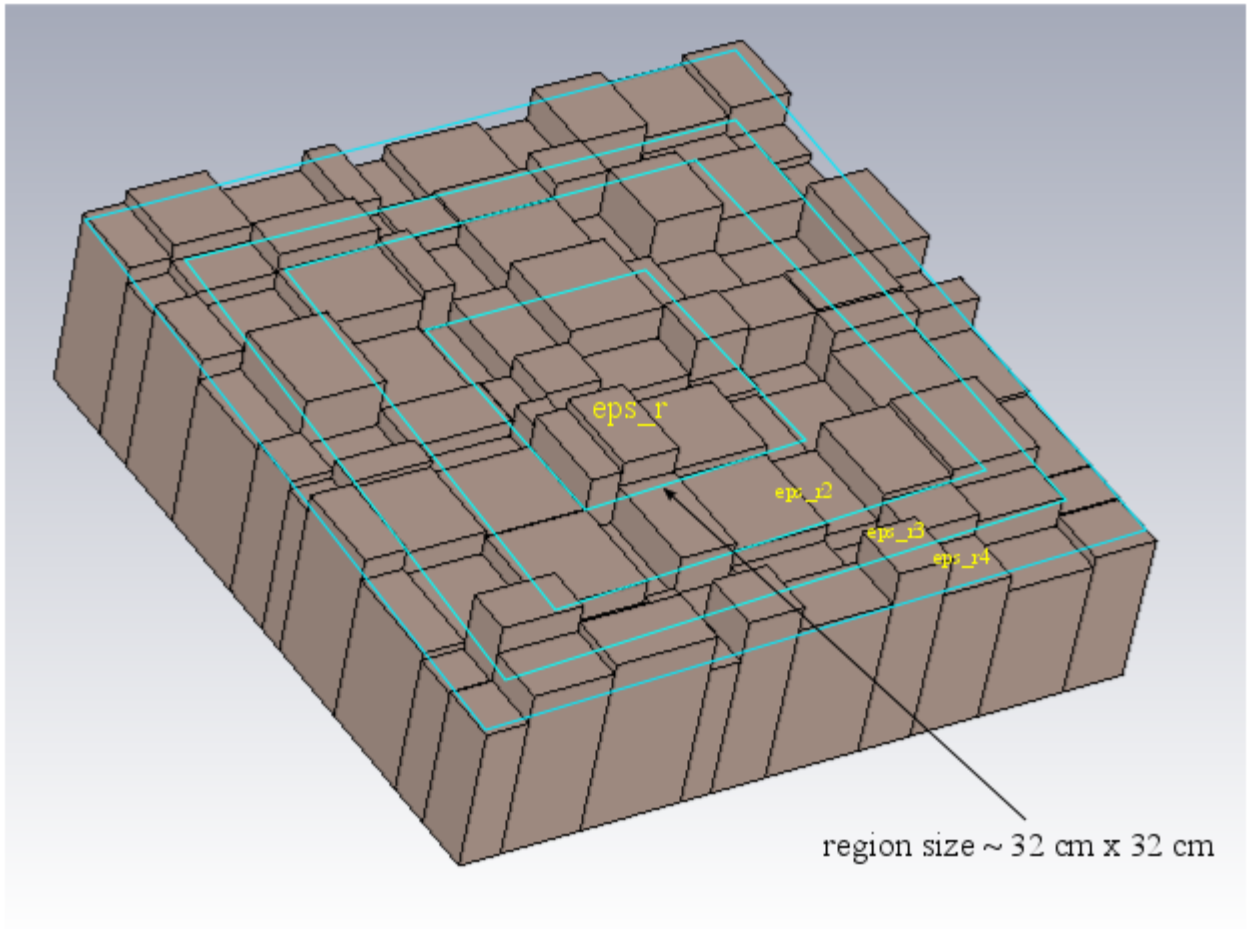
- We need a probe to measure accurately the permittivity. We need a way to measure accurately the water content.

Problem with Simulation Accuracy



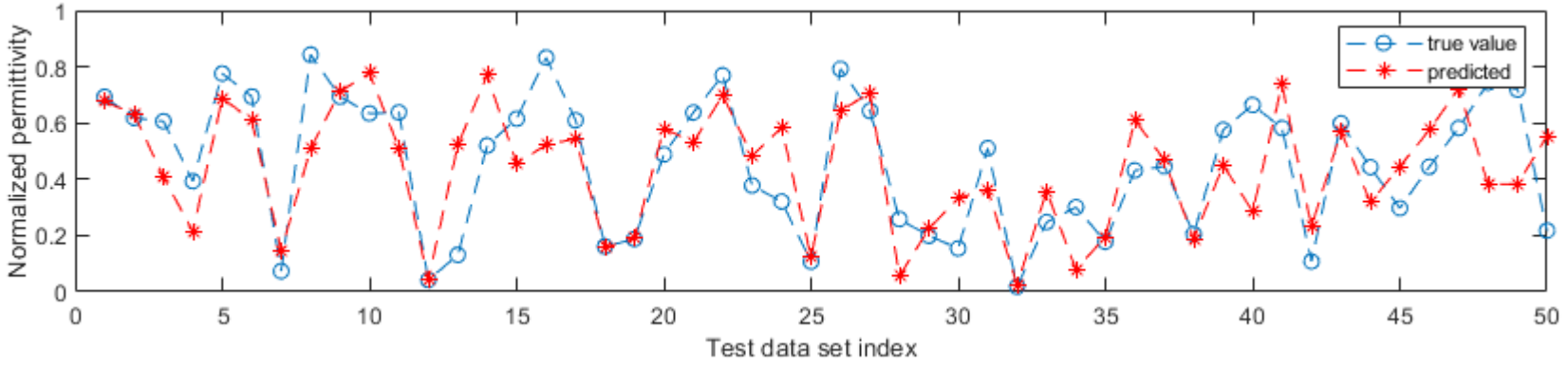
Perfect matching boundary

Results with Non-homogeneous soil

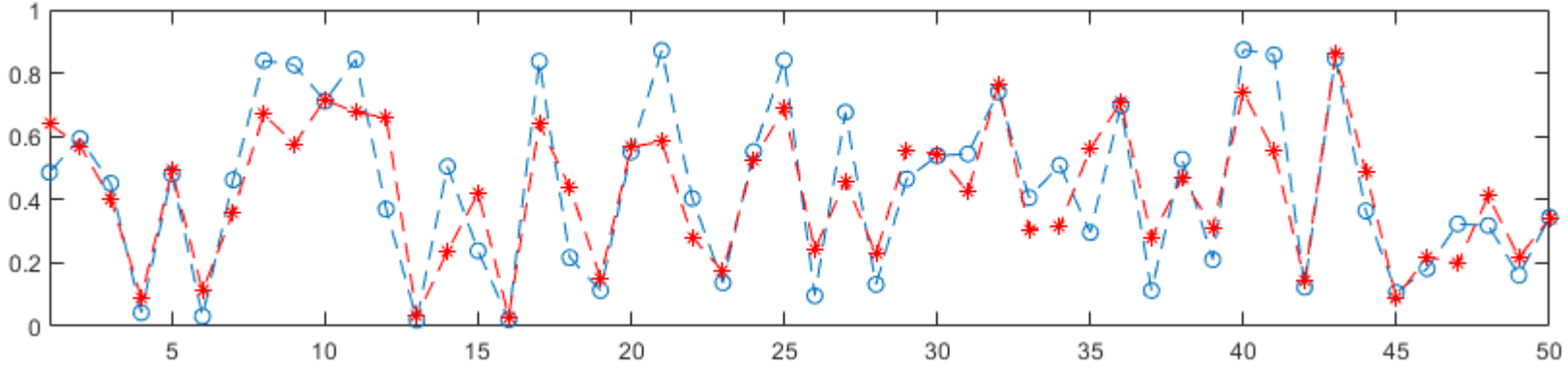


Results with Non-homogeneous soil

Check with different simulation environment



Check with different simulation environment



(2 weeks to obtain 1000 set of data)

It is working! (But with some error). The accuracy may be improved with a lot of more data.

Initial Experiment Results

Experimental Setup

Cables are fixed

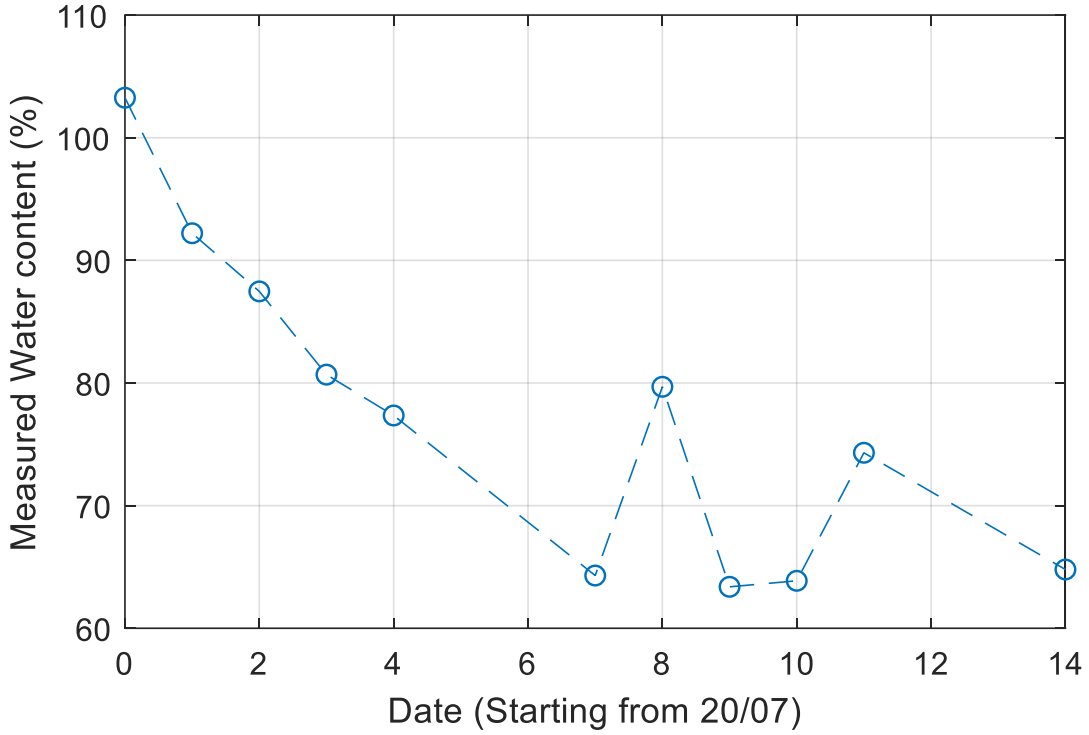
VNA with automated measurement

Two Vivaldi antennas

Mud

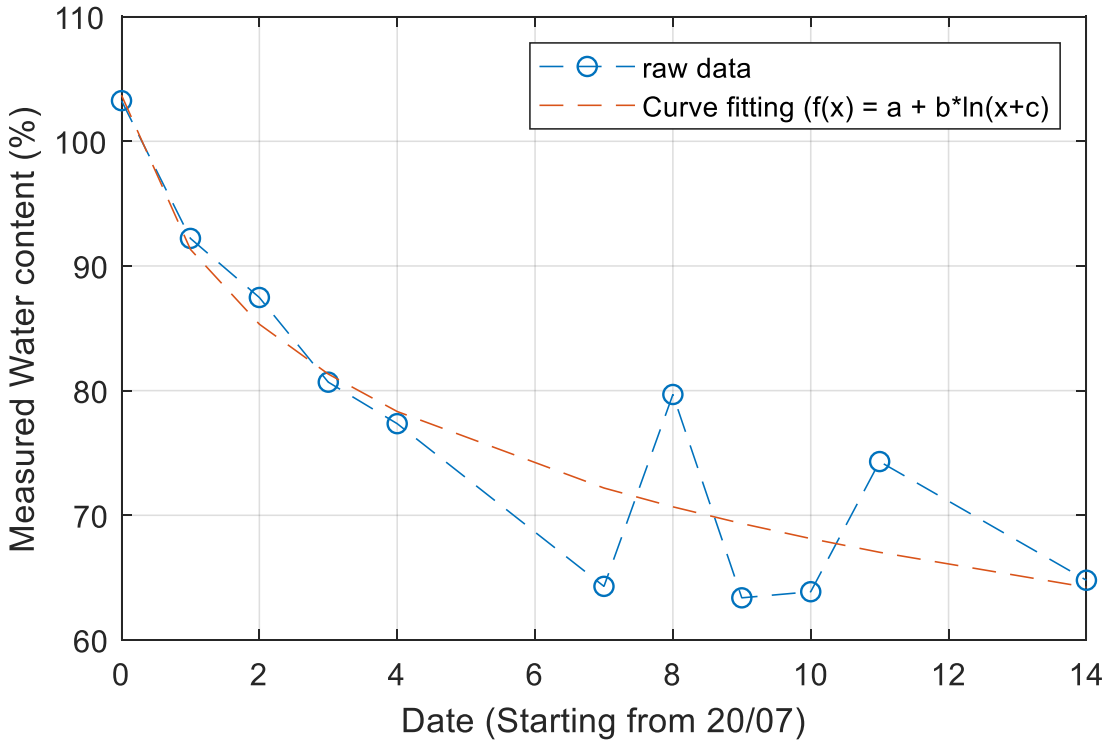
Once time a day, we use a probe to measure the permittivy of the soil at different positions
A soil sample is also stored to measure water content using gravimetric method.

Measured Water Content from Soil Sample



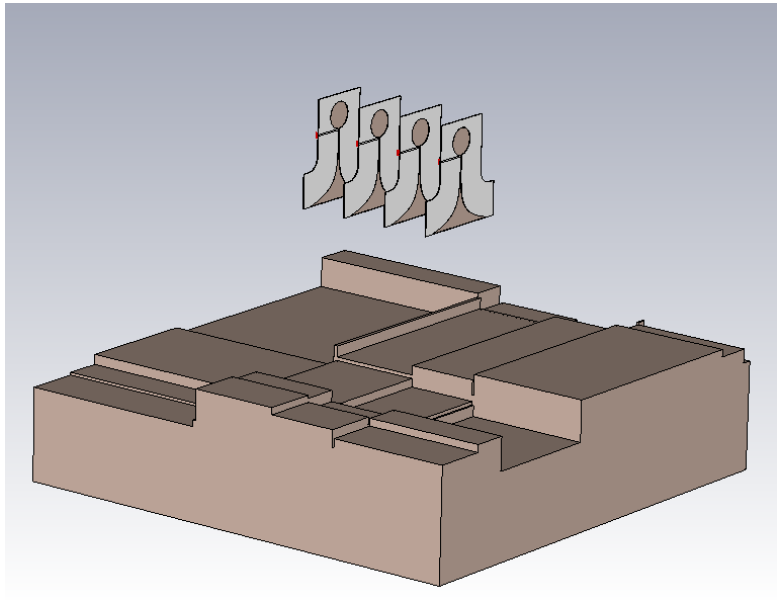
Soil sample is collected (the collecting time is recorded).
The sample is then measured by Sebastian using gravimetric measurements

Since measured data has error (water content cannot increase along the time of experiment), the water content is estimated by a **fitting function**.

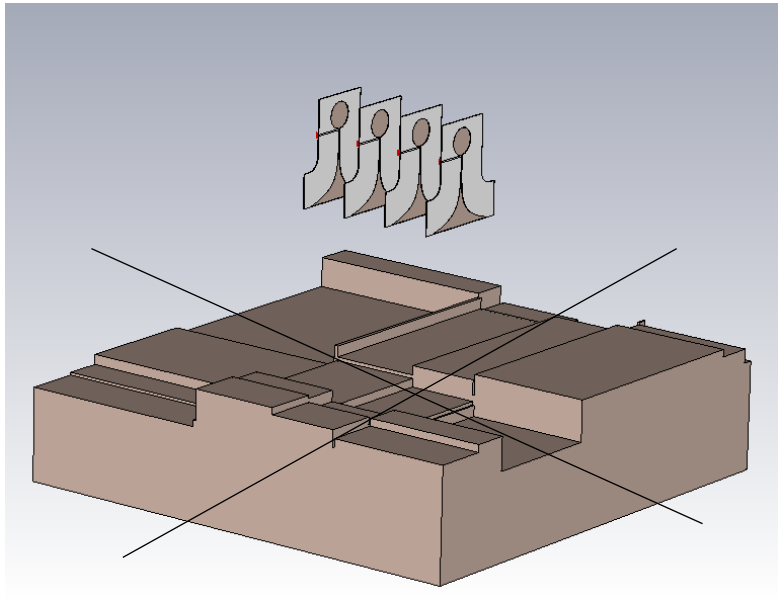


S-parameter Calibration

In simulation:



subtracts

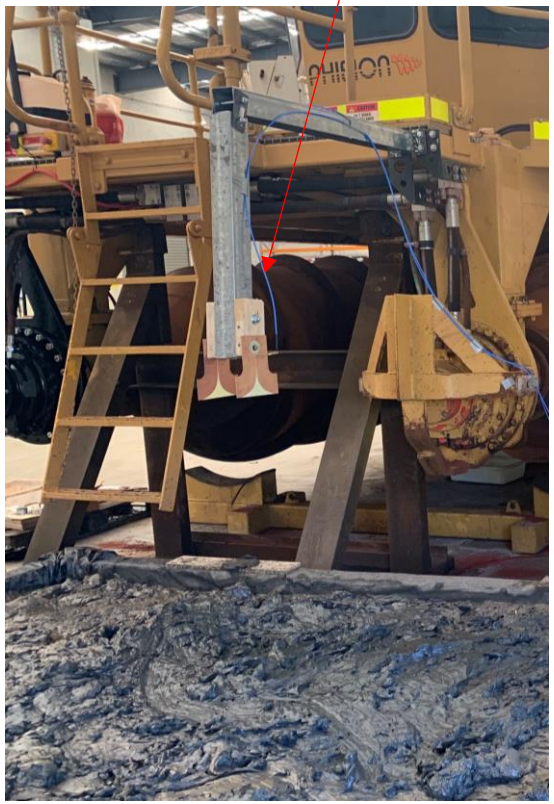


(without the soil, i.e. the antenna radiates in free-space without any obstacle)

By doing this, we obtain the data that only contains the useful information from the reflection of the soil (internal reflection of the soil and direct coupling between antenna are removed)

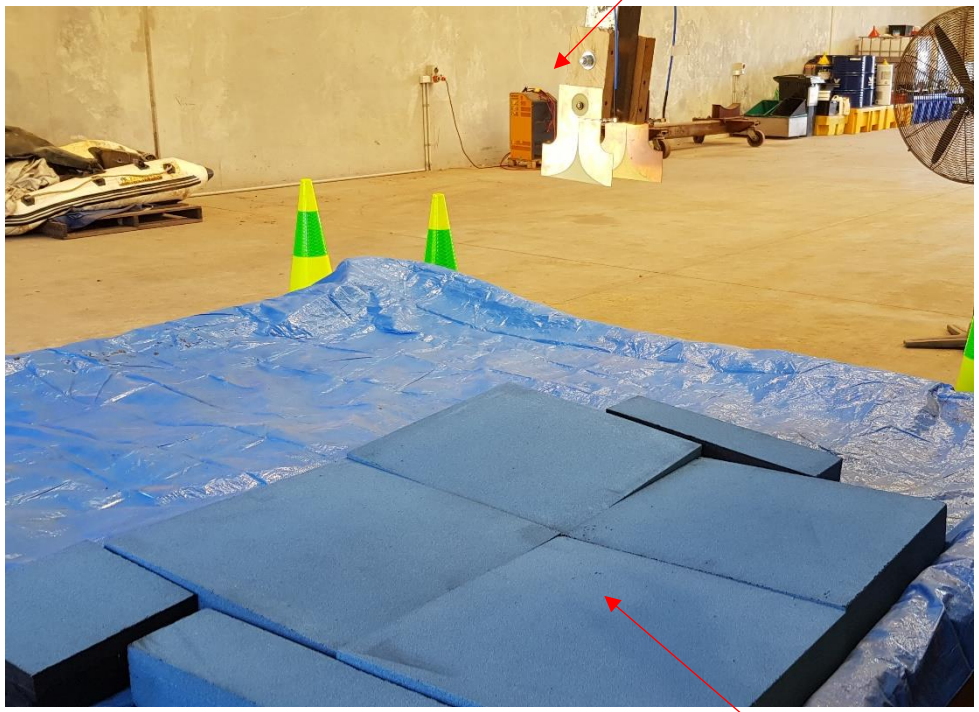
S-parameter Calibration

antennas



subtracts

antennas



absorbers

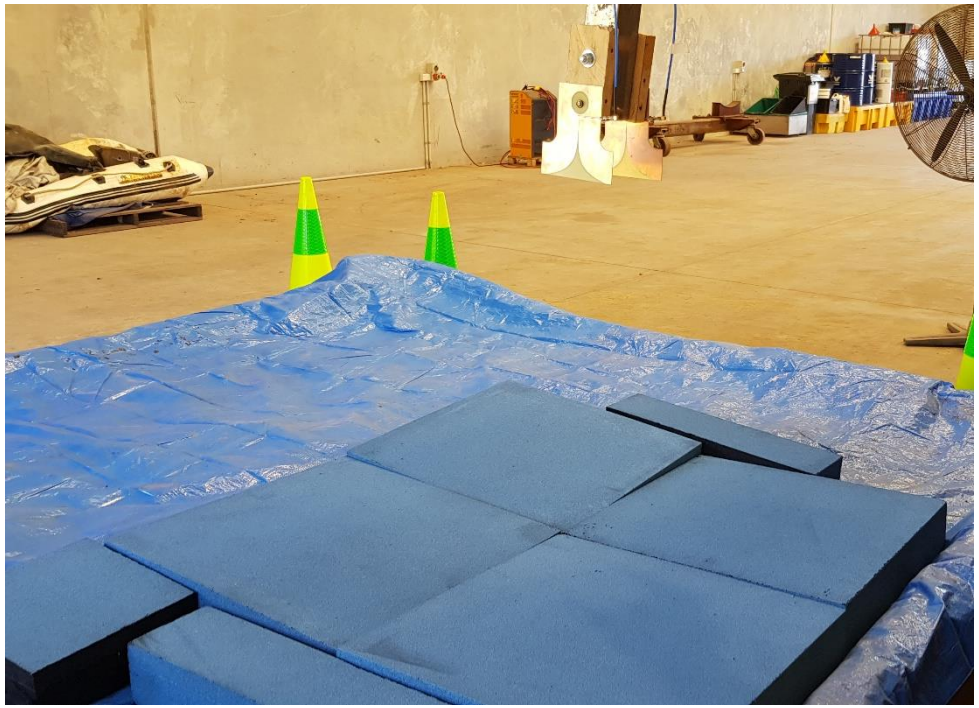
Using absorber is equivalent to removing the soil

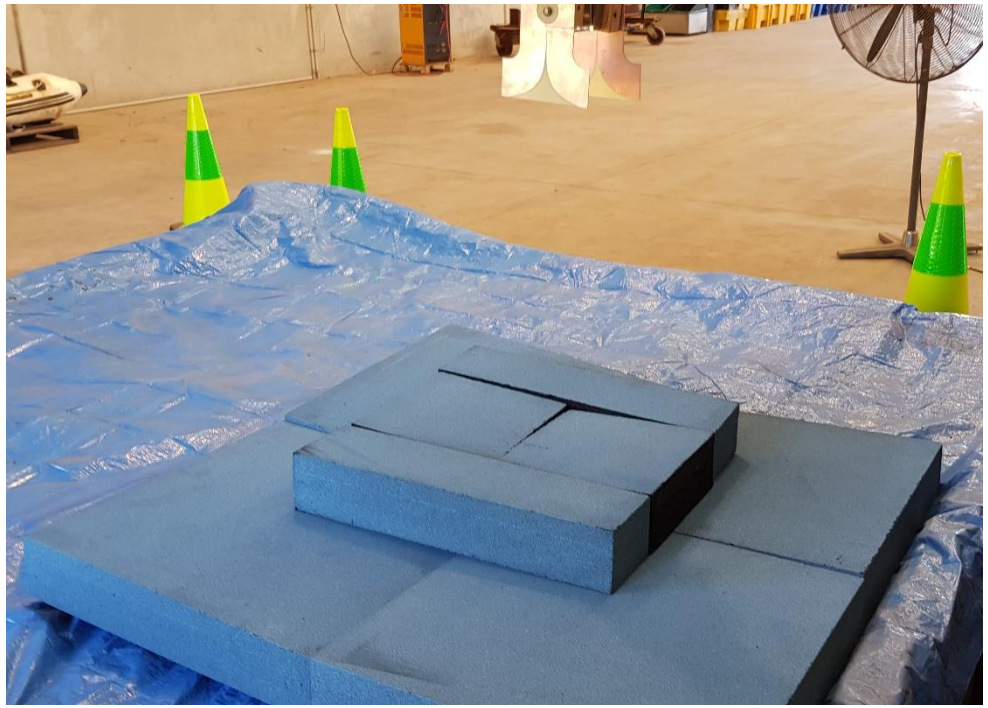
By doing this, we also “calibrate” (or remove) the effects from all other things around, e.g. mud master, cables, etc.

S-parameter Calibration

The calibration is not perfect as:

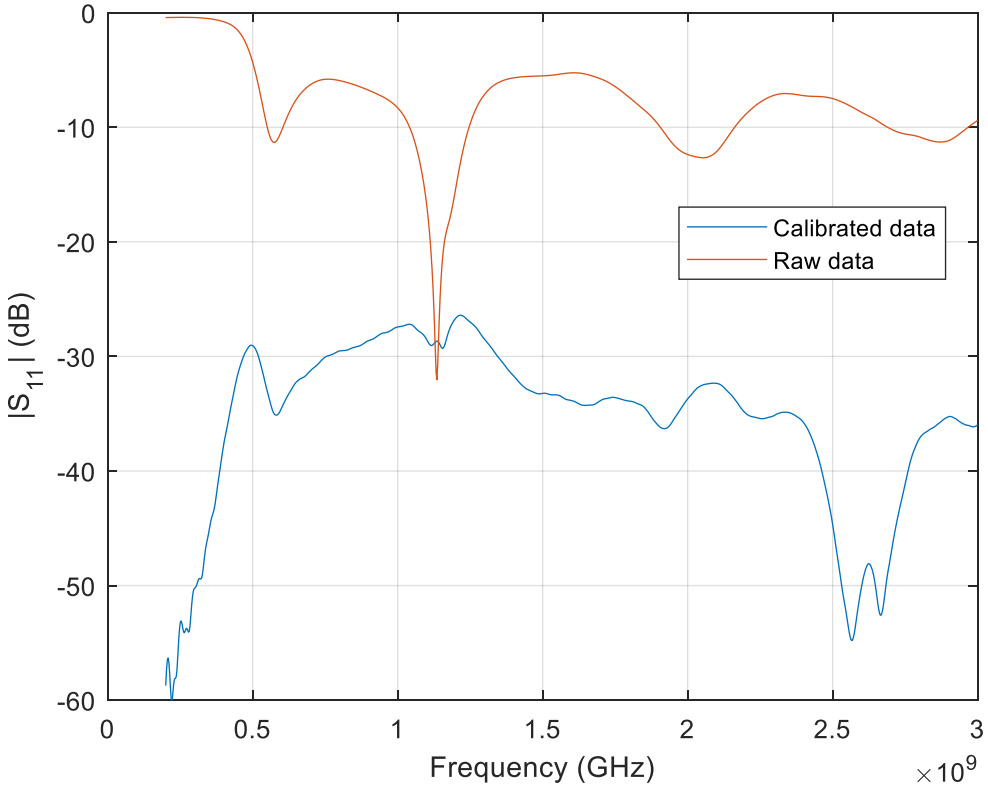
- The absorber is not perfect.
- The effect from surrounding environment is complicated with large amount of scattering signals



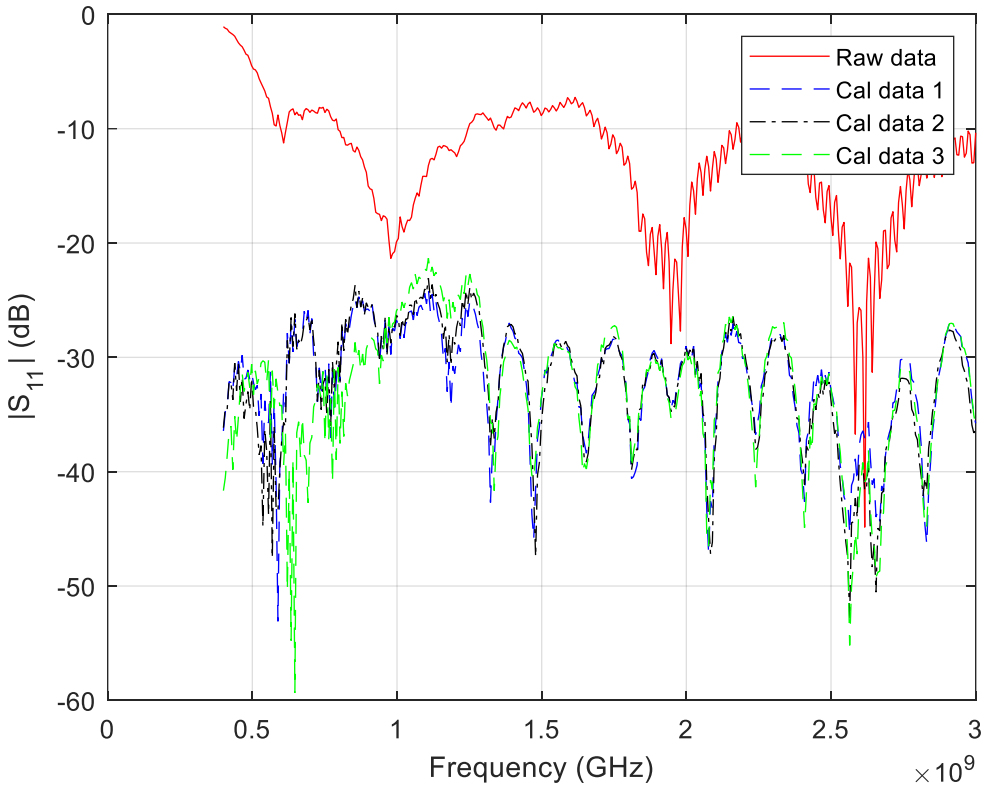


Two arrangement of absorbers were tried and each of them provides quite different calibrated data

Calibrated S-parameters



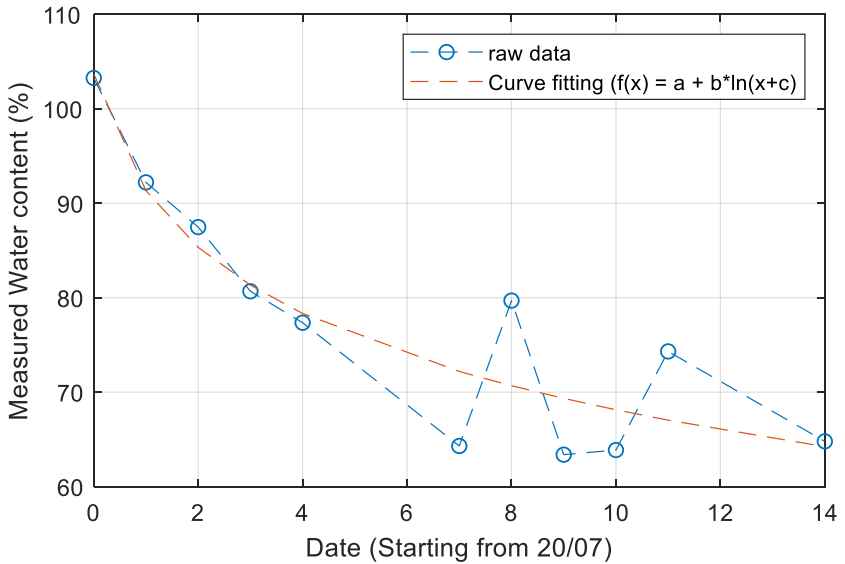
Simulation



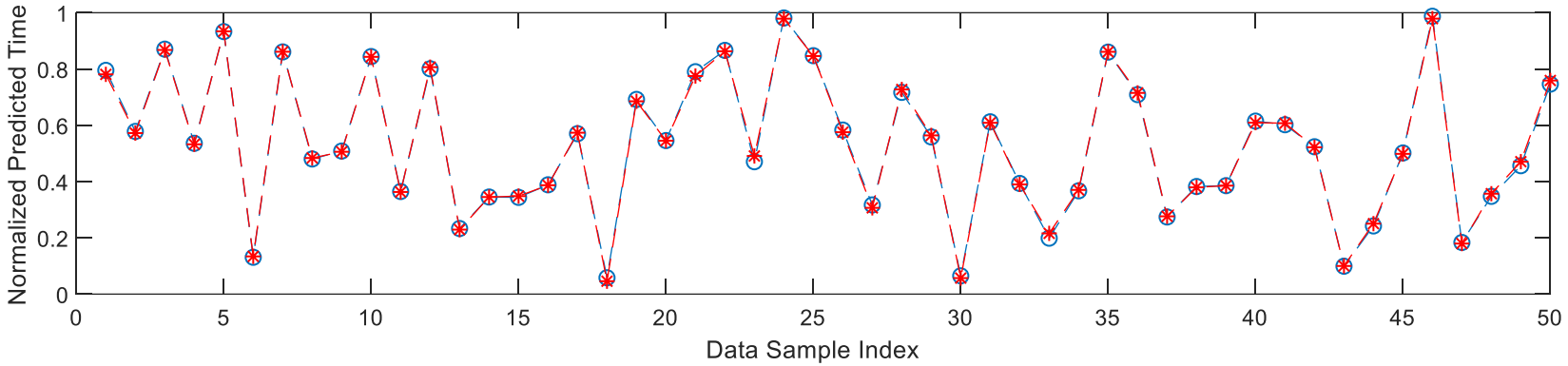
Measurement

Neural Network

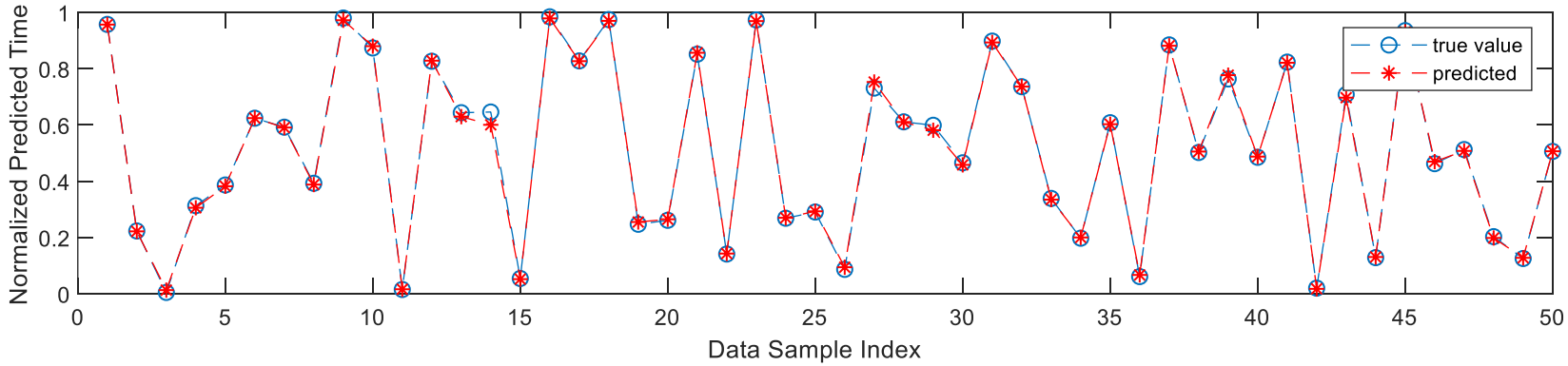
- Calibrated data is separated into two sets of data: **training set** and **testing set**.
- Data is collected from 20/07 to 06/08 with 1419 set of data. Along this time, we keep changing the surface of the soil.
- As water content is gradually decreases along the time, for the first test, the predicted quantity, or the output (**y**), is **the time at which the data is collected**



Training Data

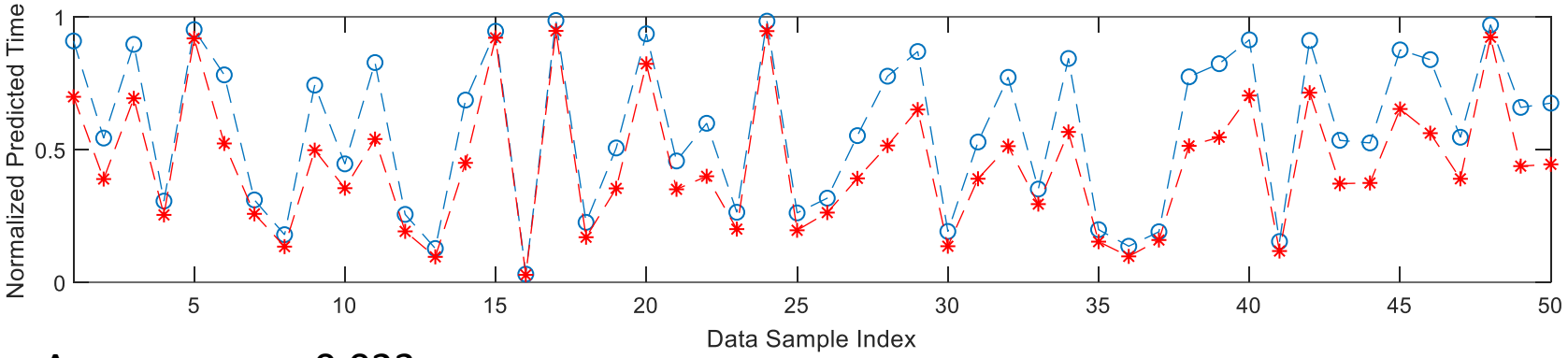


Testing Data

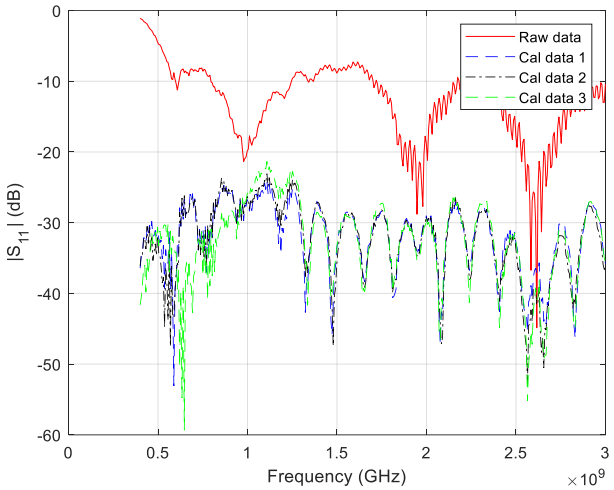


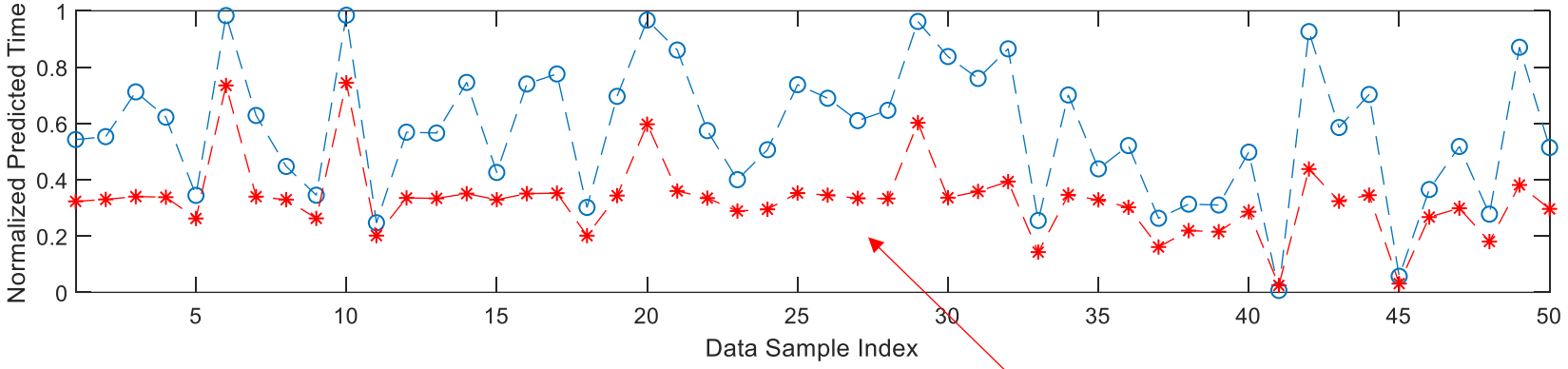
Average Error: 1e-5 (extremely accurate)

Test on Data with **different Calibrations**.



Average error: 0.023





Average error: 0.075

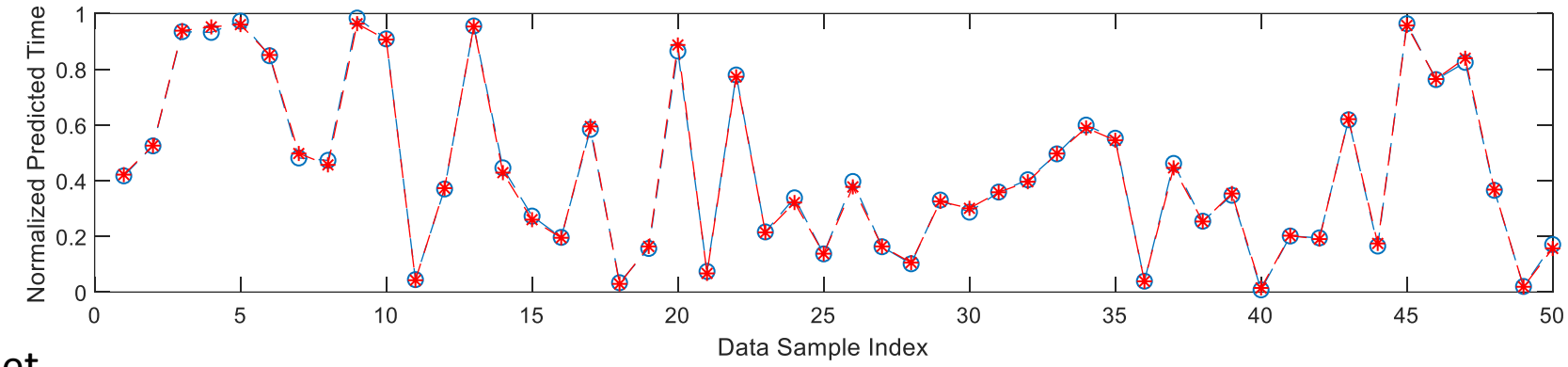
Can be corrected by scaling factor

Combine all set of data with different calibrations

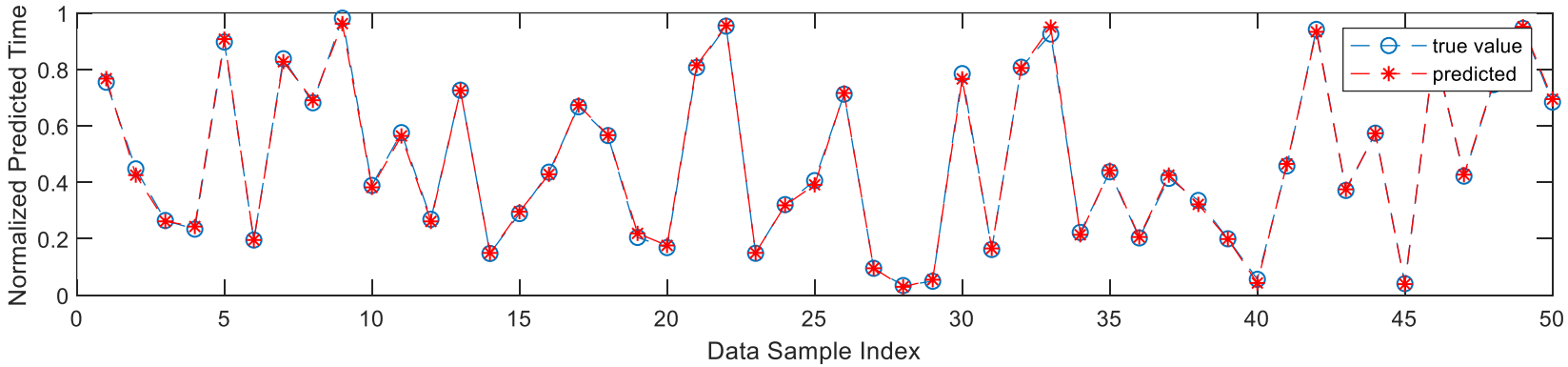
Total set of data before: 1619

Total set of data after combining: 3*1619 = 4857

Training Set



Testing Set



Average Error: 1e-4 (extremely accurate)

-> This Neural Network is much more robust to the error in calibration