

# calibration\_analysis

February 12, 2020

## 1 Calibration For This Observation

This document is a standard calibration notebook meant to show the calibration solutions for this particular observation. It also serves as a standard template for performing similar analyses on any calibration observation.

```
[1]: %matplotlib inline
import matplotlib.pyplot as plt

import datetime
import os
```

```
[31]: !echo "Analysis Performed by: $(git config --get user.name)"
print("          on:", datetime.datetime.now())
print("          Directory:", os.path.basename(os.path.dirname(os.getcwd())))
```

```
Analysis Performed by: Steven Murray
          on: 2020-02-11 14:27:37.422756
          Directory: Receiver01_2020_01_09_040_to_200MHz
```

### 1.0.1 Imports and Setup

```
[3]: from edges_io import io
from edges_cal import CalibrationObservation
```

```
[4]: def print_dep_versions(extras=None, ignore=None):
    """
    Prints versions of all important "active" modules.
    This includes modules that are not explicitly imported, as they *may* be
    →used as
    deps of used packages. It will skip any module that isn't installed at all
    →(since
    obviously this is not being used).
    :param extras: Any extra modules that may be useful for this particular
    →notebook.
    """
```

```

from importlib import import_module

MODULES = [
    "edges_io",
    "edges_cal",
    "read_acq",
    "scipy",
    "numpy",
    "h5py"
]

ignore = ignore or []

if extras is not None:
    MODULES += extras

for module in MODULES:
    if module in ignore:
        continue

    try:
        _mdl = import_module(module)
        print("Module {:<11}...\tVersion {:<7}".format(module, _mdl.
→__version__))
    except ModuleNotFoundError:
        pass

```

```
[5]: print_dep_versions()
```

```

Module edges_io ... Version 0.2.0.post0.dev6+gab5b32e
Module edges_cal ... Version 0.3.0.post0.dev1+g5b9161c.dirty
Module read_acq ... Version 0.3.1.dev1+g7f2676e
Module scipy ... Version 1.4.1
Module numpy ... Version 1.18.1
Module h5py ... Version 2.9.0

```

## 1.1 Define the Observation

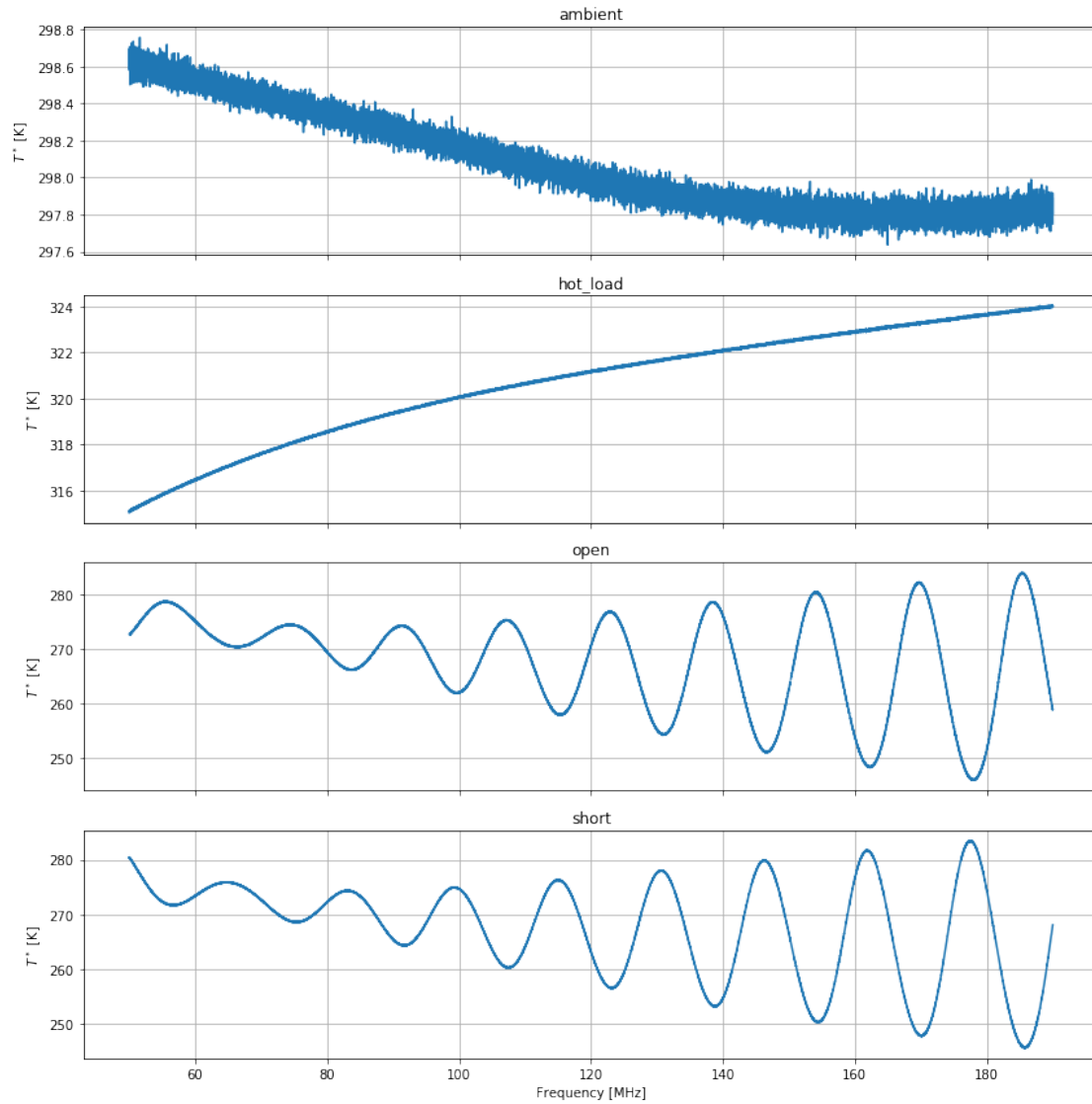
```
[15]: calobs = CalibrationObservation(
    path = '../',
    ambient_temp=25,
    f_low = 50.0,
    f_high = 190.0,
    run_num = None, # chooses the "latest" run_num for each source
    repeat_num = None, # chooses the "latest" repeat_num for each source
    resistance_f=49.9859,
```

```
resistance_m=50.1555,  
ignore_times_percent=10,  
cterms=10,  
wterms=12,  
cache_dir='derived'  
)
```

```
Checking root folder: /data5/edges/data/CalibrationObservations/Receiver01_2  
020_01_09_040_to_200MHz/25C  
Checking S11 folder contents at /data5/edges/data/CalibrationObservations/Re  
ceiver01_2020_01_09_040_to_200MHz/25C/S11  
Checking Spectra folder contents at /data5/edges/data/CalibrationObservation  
s/Receiver01_2020_01_09_040_to_200MHz/25C/Spectra  
Checking Resistances folder contents at /data5/edges/data/CalibrationObserva  
tions/Receiver01_2020_01_09_040_to_200MHz/25C/Resistance  
Checking Spectra folder contents at /data5/edges/data/CalibrationObservation  
s/Receiver01_2020_01_09_040_to_200MHz/25C/Spectra  
Checking Resistances folder contents at /data5/edges/data/CalibrationObserva  
tions/Receiver01_2020_01_09_040_to_200MHz/25C/Resistance  
Checking S11 folder contents at /data5/edges/data/CalibrationObservations/Re  
ceiver01_2020_01_09_040_to_200MHz/25C/S11
```

## 1.2 Perform Nominal Calibration

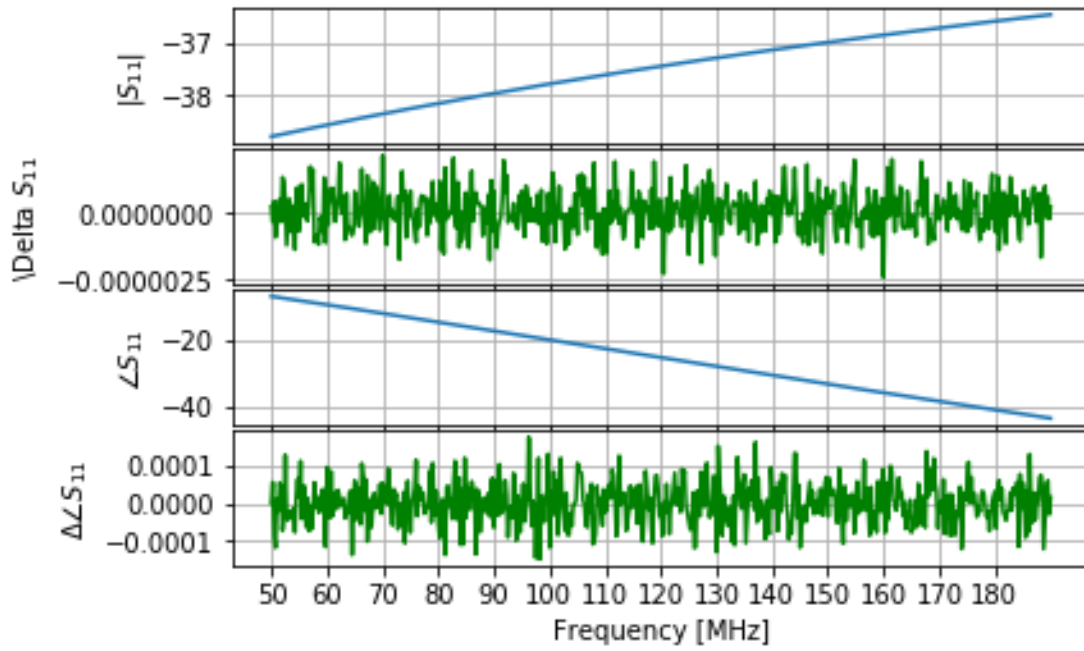
```
[16]: fig, ax = plt.subplots(4, 1, figsize=(12,12), sharex=True)  
calobs.plot_raw_spectra(fig, ax)  
fig.tight_layout()
```



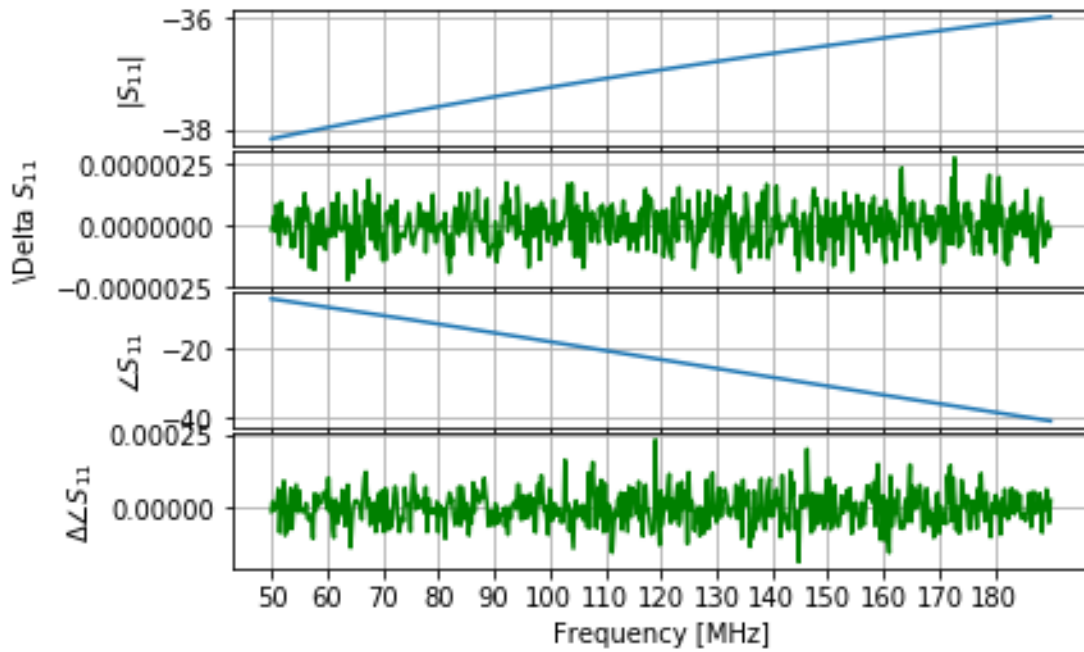
**Figure 1** | Uncalibrated (but 3-position-switch corrected) spectra for the four input sources.

```
[17]: calobs.plot_s11_models();
```

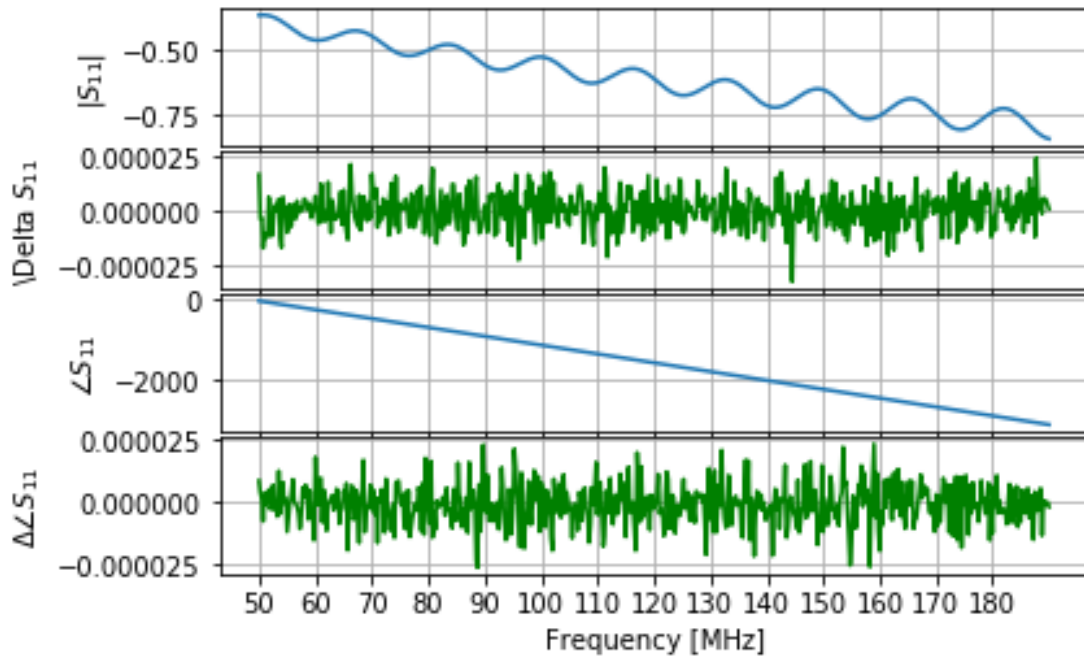
### ambient Reflection Coefficient Models



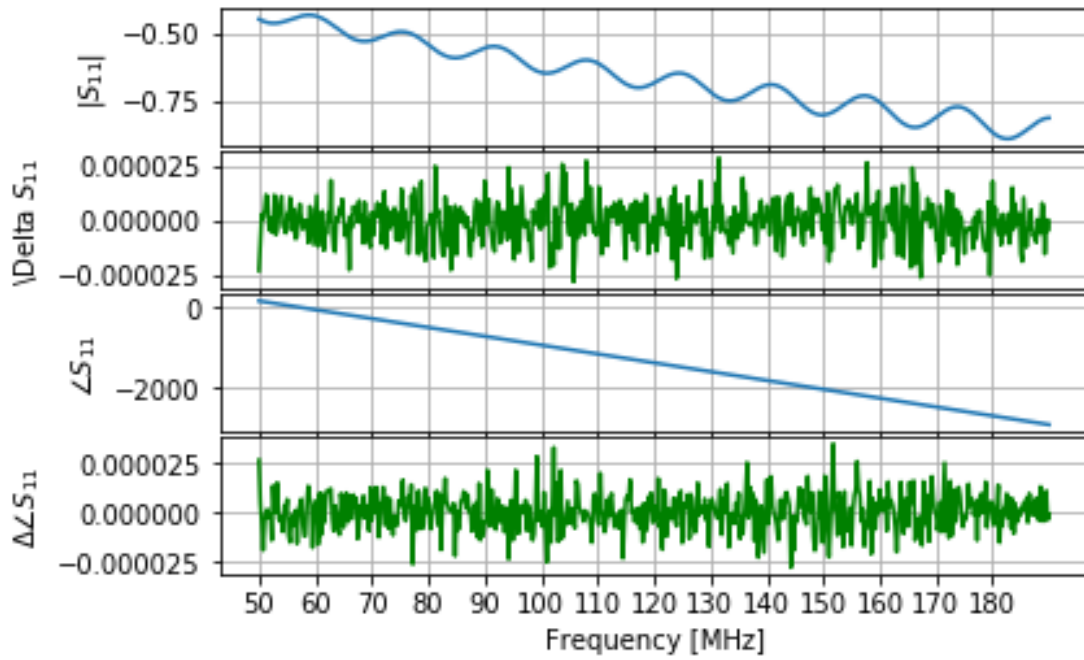
### hot\_load Reflection Coefficient Models



### open Reflection Coefficient Models

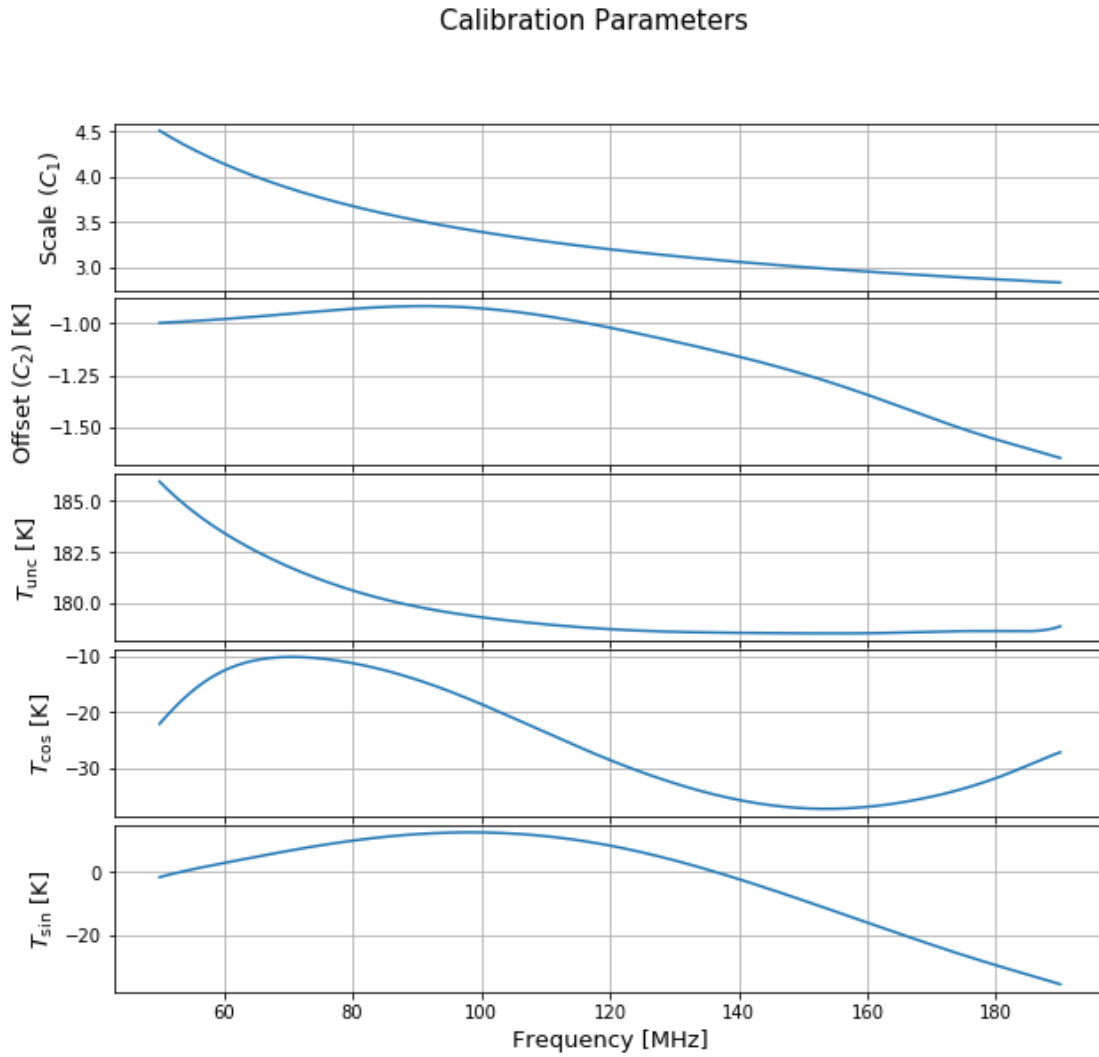


### short Reflection Coefficient Models



**Figure 2** |  $S_{11}$  models for each of the input sources, with their residuals.

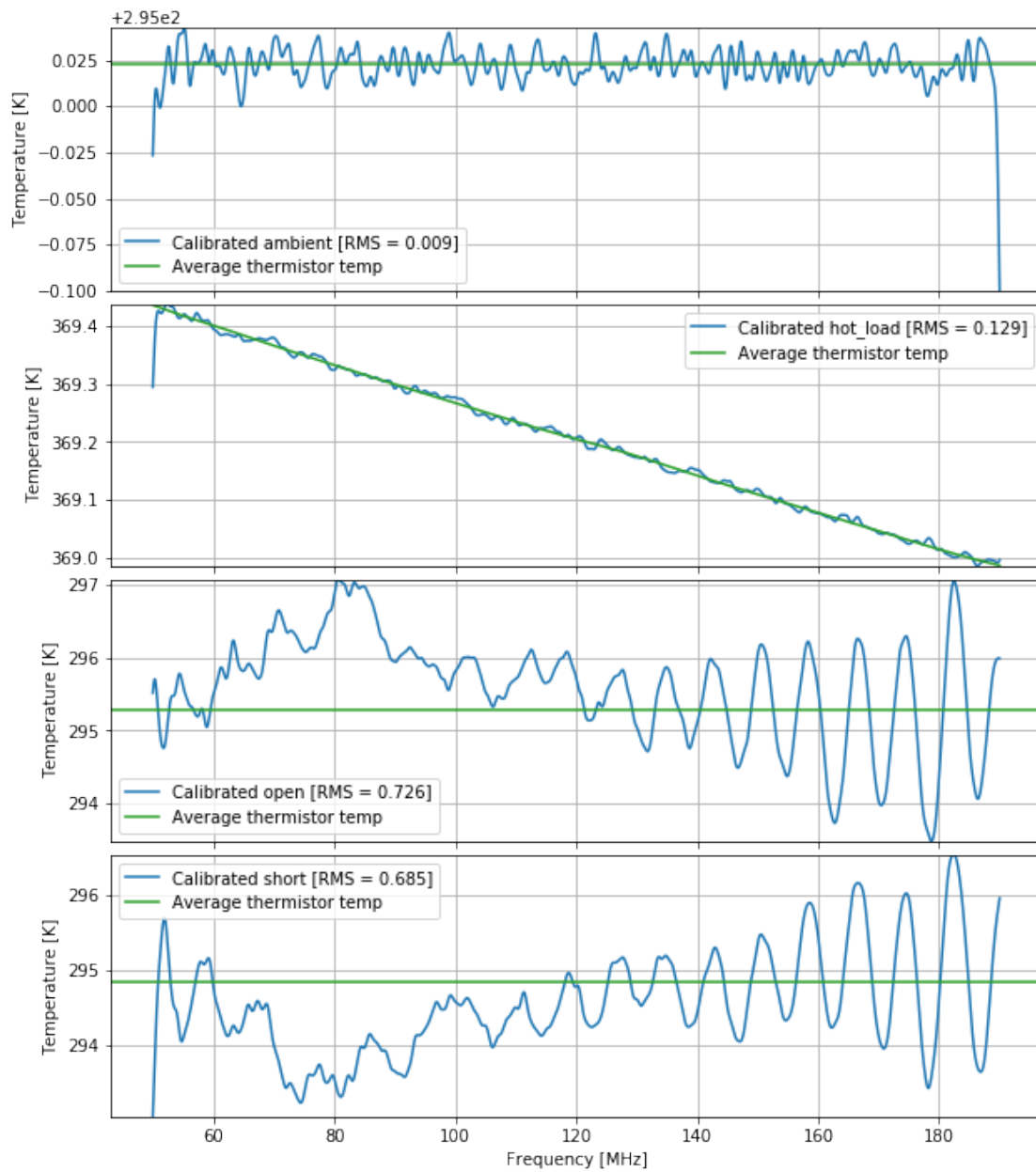
```
[18]: calobs.plot_coefficients();
```



**Figure 3** | Calibration parameters for this dataset as a function of frequency, gained with the nominal number of C-terms and W-terms, using the iterative fitting procedure.

```
[19]: calobs.plot_calibrated_temps();
```

### Calibrated Temperatures for Calibration Sources



**Figure 4** | Calibrated temperature for each of the inputs. Green lines show the known input temperature. The Open and Short fits are unsatisfactory here.



### 1.3 Sweep of Number of Parameters

Now we try sweeping over the number of parameters to see if we can minimise the RMS.

```
[14]: rms_per_param = {}
for cterms in range(8, 16):
    for wterms in range(8, 16):
        calobs.update(cterms=cterms, wterms=wterms)
        print(f"Nc = {cterms}, Nw = {wterms}")
        unsmoothed = calobs.get_rms(smooth=0)
        print(f"    Smoothed RMS [mK]: {'', '.join(f'{name}: {1000*val:.2f}'')
↳for name, val in calobs.get_rms().items())} # Default smoothed
↳over four adjacent bins
        print(f"    Unsmoothed RMS [mK]: {'', '.join(f'{name}: {1000*val:.2f}'')
↳for name, val in unsmoothed.items())} # Not smoothed

        full_rms = sum(unsmoothed.values())
        rms_per_param[(cterms, wterms)] = full_rms / (2*cterms + 3*wterms)
        print(f"    RMS per param: {1000*rms_per_param[(cterms, wterms)]:.2f}
↳mK")
```

Nc = 8, Nw = 8

Smoothed RMS: ambient: 35.01, hot\_load: 19.66, open: 956.42, short: 877.00

Unsmoothed RMS: ambient: 131.00, hot\_load: 71.43, open: 1456.00, short:

1354.97

Nc = 8, Nw = 9

Smoothed RMS: ambient: 34.97, hot\_load: 19.54, open: 919.18, short: 866.78

Unsmoothed RMS: ambient: 130.99, hot\_load: 71.40, open: 1431.44, short:

1348.36

Nc = 8, Nw = 10

Smoothed RMS: ambient: 34.97, hot\_load: 19.54, open: 919.99, short: 866.33

Unsmoothed RMS: ambient: 130.99, hot\_load: 71.40, open: 1431.93, short:

1348.07

Nc = 8, Nw = 11

Smoothed RMS: ambient: 34.97, hot\_load: 19.53, open: 895.09, short: 828.31

Unsmoothed RMS: ambient: 130.99, hot\_load: 71.39, open: 1416.12, short:

1323.97

Nc = 8, Nw = 12

Smoothed RMS: ambient: 34.96, hot\_load: 19.56, open: 860.03, short: 805.61

Unsmoothed RMS: ambient: 130.99, hot\_load: 71.40, open: 1394.16, short:

1309.91

Nc = 8, Nw = 13

Smoothed RMS: ambient: 35.00, hot\_load: 19.56, open: 833.61, short: 749.31

Unsmoothed RMS: ambient: 131.00, hot\_load: 71.40, open: 1377.43, short:

1276.03

Nc = 8, Nw = 14

Smoothed RMS: ambient: 34.98, hot\_load: 19.64, open: 775.42, short: 728.15

Unsmoothed RMS: ambient: 130.99, hot\_load: 71.42, open: 1342.70, short:

1263.77  
Nc = 8, Nw = 15  
Smoothed RMS: ambient: 35.02, hot\_load: 19.65, open: 774.26, short: 677.65  
Unsmoothed RMS: ambient: 131.00, hot\_load: 71.42, open: 1341.88, short:

1235.33  
Nc = 9, Nw = 8  
Smoothed RMS: ambient: 34.91, hot\_load: 19.21, open: 957.30, short: 877.48  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.31, open: 1456.58, short:

1355.29  
Nc = 9, Nw = 9  
Smoothed RMS: ambient: 34.91, hot\_load: 19.21, open: 919.22, short: 866.90  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.31, open: 1431.46, short:

1348.44  
Nc = 9, Nw = 10  
Smoothed RMS: ambient: 34.91, hot\_load: 19.21, open: 919.96, short: 866.40  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.31, open: 1431.92, short:

1348.12  
Nc = 9, Nw = 11  
Smoothed RMS: ambient: 34.91, hot\_load: 19.21, open: 894.96, short: 828.20  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.31, open: 1416.03, short:

1323.90  
Nc = 9, Nw = 12  
Smoothed RMS: ambient: 34.89, hot\_load: 19.23, open: 860.02, short: 805.60  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.31, open: 1394.16, short:

1309.90  
Nc = 9, Nw = 13  
Smoothed RMS: ambient: 34.95, hot\_load: 19.28, open: 833.61, short: 749.31  
Unsmoothed RMS: ambient: 130.98, hot\_load: 71.33, open: 1377.43, short:

1276.03  
Nc = 9, Nw = 14  
Smoothed RMS: ambient: 34.92, hot\_load: 19.34, open: 775.42, short: 728.14  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.34, open: 1342.71, short:

1263.77  
Nc = 9, Nw = 15  
Smoothed RMS: ambient: 34.99, hot\_load: 19.47, open: 774.25, short: 677.65  
Unsmoothed RMS: ambient: 130.99, hot\_load: 71.37, open: 1341.88, short:

1235.33  
Nc = 10, Nw = 8  
Smoothed RMS: ambient: 34.90, hot\_load: 19.17, open: 957.00, short: 877.50  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1456.39, short:

1355.30  
Nc = 10, Nw = 9  
Smoothed RMS: ambient: 34.90, hot\_load: 19.17, open: 919.12, short: 866.98  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1431.39, short:

1348.49  
Nc = 10, Nw = 10  
Smoothed RMS: ambient: 34.90, hot\_load: 19.17, open: 919.75, short: 866.41  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1431.79, short:

1348.13  
Nc = 10, Nw = 11  
Smoothed RMS: ambient: 34.91, hot\_load: 19.17, open: 894.96, short: 828.26  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1416.03, short:

1323.94  
Nc = 10, Nw = 12  
Smoothed RMS: ambient: 34.89, hot\_load: 19.18, open: 860.05, short: 805.67  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1394.17, short:

1309.94  
Nc = 10, Nw = 13  
Smoothed RMS: ambient: 34.95, hot\_load: 19.23, open: 833.61, short: 749.30  
Unsmoothed RMS: ambient: 130.98, hot\_load: 71.31, open: 1377.43, short:

1276.03  
Nc = 10, Nw = 14  
Smoothed RMS: ambient: 34.91, hot\_load: 19.28, open: 775.41, short: 728.14  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.32, open: 1342.70, short:

1263.77  
Nc = 10, Nw = 15  
Smoothed RMS: ambient: 34.99, hot\_load: 19.41, open: 774.25, short: 677.65  
Unsmoothed RMS: ambient: 130.99, hot\_load: 71.36, open: 1341.88, short:

1235.33  
Nc = 11, Nw = 8  
Smoothed RMS: ambient: 34.91, hot\_load: 19.17, open: 956.05, short: 876.88  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1455.77, short:

1354.90  
Nc = 11, Nw = 9  
Smoothed RMS: ambient: 34.91, hot\_load: 19.17, open: 918.06, short: 866.59  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1430.73, short:

1348.24  
Nc = 11, Nw = 10  
Smoothed RMS: ambient: 34.91, hot\_load: 19.17, open: 918.67, short: 866.00  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1431.11, short:

1347.86  
Nc = 11, Nw = 11  
Smoothed RMS: ambient: 34.91, hot\_load: 19.17, open: 894.95, short: 828.33  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1416.02, short:

1323.99  
Nc = 11, Nw = 12  
Smoothed RMS: ambient: 34.89, hot\_load: 19.18, open: 860.04, short: 805.66  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1394.17, short:

1309.94  
Nc = 11, Nw = 13  
Smoothed RMS: ambient: 34.95, hot\_load: 19.23, open: 833.56, short: 749.28  
Unsmoothed RMS: ambient: 130.98, hot\_load: 71.31, open: 1377.40, short:

1276.01  
Nc = 11, Nw = 14  
Smoothed RMS: ambient: 34.91, hot\_load: 19.28, open: 775.41, short: 728.14  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.32, open: 1342.71, short:

1263.77  
Nc = 11, Nw = 15  
Smoothed RMS: ambient: 34.98, hot\_load: 19.40, open: 774.25, short: 677.65  
Unsmoothed RMS: ambient: 130.99, hot\_load: 71.36, open: 1341.88, short:

1235.33  
Nc = 12, Nw = 8  
Smoothed RMS: ambient: 34.88, hot\_load: 19.18, open: 958.57, short: 874.67  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1457.50, short:

1353.46  
Nc = 12, Nw = 9  
Smoothed RMS: ambient: 34.88, hot\_load: 19.18, open: 917.36, short: 867.15  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1430.40, short:

1348.59  
Nc = 12, Nw = 10  
Smoothed RMS: ambient: 34.88, hot\_load: 19.18, open: 917.71, short: 866.48  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1430.62, short:

1348.17  
Nc = 12, Nw = 11  
Smoothed RMS: ambient: 34.88, hot\_load: 19.18, open: 896.93, short: 828.28  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1417.37, short:

1323.95  
Nc = 12, Nw = 12  
Smoothed RMS: ambient: 34.88, hot\_load: 19.18, open: 860.35, short: 805.89  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.30, open: 1394.37, short:

1310.08  
Nc = 12, Nw = 13  
Smoothed RMS: ambient: 34.93, hot\_load: 19.24, open: 833.42, short: 749.05  
Unsmoothed RMS: ambient: 130.98, hot\_load: 71.31, open: 1377.32, short:

1275.88  
Nc = 12, Nw = 14  
Smoothed RMS: ambient: 34.90, hot\_load: 19.27, open: 775.42, short: 727.98  
Unsmoothed RMS: ambient: 130.97, hot\_load: 71.32, open: 1342.71, short:

1263.68  
Nc = 12, Nw = 15  
Smoothed RMS: ambient: 34.97, hot\_load: 19.40, open: 774.28, short: 677.66  
Unsmoothed RMS: ambient: 130.99, hot\_load: 71.36, open: 1341.90, short:

1235.33  
Nc = 13, Nw = 8  
Smoothed RMS: ambient: 34.82, hot\_load: 19.14, open: 958.39, short: 878.32  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1457.40, short:

1355.83  
Nc = 13, Nw = 9  
Smoothed RMS: ambient: 34.82, hot\_load: 19.14, open: 918.78, short: 869.37  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1431.31, short:

1350.02  
Nc = 13, Nw = 10  
Smoothed RMS: ambient: 34.82, hot\_load: 19.14, open: 919.10, short: 868.61  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1431.52, short:

1349.53  
Nc = 13, Nw = 11  
Smoothed RMS: ambient: 34.82, hot\_load: 19.14, open: 898.13, short: 831.07  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1418.17, short:

1325.70  
Nc = 13, Nw = 12  
Smoothed RMS: ambient: 34.82, hot\_load: 19.14, open: 863.65, short: 807.86  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1396.46, short:

1311.29  
Nc = 13, Nw = 13  
Smoothed RMS: ambient: 34.82, hot\_load: 19.13, open: 833.12, short: 749.14  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1377.15, short:

1275.93  
Nc = 13, Nw = 14  
Smoothed RMS: ambient: 34.80, hot\_load: 19.18, open: 775.47, short: 728.02  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.30, open: 1342.74, short:

1263.70  
Nc = 13, Nw = 15  
Smoothed RMS: ambient: 34.81, hot\_load: 19.22, open: 774.40, short: 677.71  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.31, open: 1341.96, short:

1235.36  
Nc = 14, Nw = 8  
Smoothed RMS: ambient: 34.80, hot\_load: 19.13, open: 959.98, short: 879.41  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1458.58, short:

1356.53  
Nc = 14, Nw = 9  
Smoothed RMS: ambient: 34.80, hot\_load: 19.13, open: 918.03, short: 872.61  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1431.01, short:

1352.11  
Nc = 14, Nw = 10  
Smoothed RMS: ambient: 34.80, hot\_load: 19.13, open: 918.43, short: 871.73  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1431.27, short:

1351.54  
Nc = 14, Nw = 11  
Smoothed RMS: ambient: 34.80, hot\_load: 19.13, open: 896.52, short: 835.54  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1417.28, short:

1328.50  
Nc = 14, Nw = 12  
Smoothed RMS: ambient: 34.80, hot\_load: 19.13, open: 861.17, short: 811.66  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1395.06, short:

1313.63  
Nc = 14, Nw = 13  
Smoothed RMS: ambient: 34.80, hot\_load: 19.13, open: 833.80, short: 752.61  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1377.69, short:

1277.97  
Nc = 14, Nw = 14  
Smoothed RMS: ambient: 34.80, hot\_load: 19.13, open: 775.48, short: 728.79  
Unsmoothed RMS: ambient: 130.95, hot\_load: 71.29, open: 1342.74, short:

```

1264.14
Nc = 14, Nw = 15
  Smoothed RMS:  ambient: 34.81, hot_load: 19.19, open: 774.08, short: 677.47
  Unsmoothed RMS: ambient: 130.95, hot_load: 71.30, open: 1341.78, short:
1235.23
Nc = 15, Nw = 8
  Smoothed RMS:  ambient: 34.80, hot_load: 19.12, open: 959.50, short: 878.88
  Unsmoothed RMS: ambient: 130.95, hot_load: 71.28, open: 1458.27, short:
1356.19
Nc = 15, Nw = 9
  Smoothed RMS:  ambient: 34.80, hot_load: 19.12, open: 917.05, short: 872.49
  Unsmoothed RMS: ambient: 130.95, hot_load: 71.28, open: 1430.40, short:
1352.04
Nc = 15, Nw = 10
  Smoothed RMS:  ambient: 34.80, hot_load: 19.12, open: 917.37, short: 871.67
  Unsmoothed RMS: ambient: 130.95, hot_load: 71.28, open: 1430.61, short:
1351.50
Nc = 15, Nw = 11
  Smoothed RMS:  ambient: 34.80, hot_load: 19.12, open: 895.52, short: 835.47
  Unsmoothed RMS: ambient: 130.95, hot_load: 71.28, open: 1416.66, short:
1328.46
Nc = 15, Nw = 12
  Smoothed RMS:  ambient: 34.80, hot_load: 19.12, open: 861.09, short: 810.79
  Unsmoothed RMS: ambient: 130.95, hot_load: 71.28, open: 1395.01, short:
1313.10
Nc = 15, Nw = 13
  Smoothed RMS:  ambient: 34.80, hot_load: 19.12, open: 833.78, short: 750.74
  Unsmoothed RMS: ambient: 130.95, hot_load: 71.28, open: 1377.65, short:
1276.87
Nc = 15, Nw = 14
  Smoothed RMS:  ambient: 34.80, hot_load: 19.12, open: 774.79, short: 726.58
  Unsmoothed RMS: ambient: 130.95, hot_load: 71.28, open: 1342.34, short:
1262.87
Nc = 15, Nw = 15
  Smoothed RMS:  ambient: 34.80, hot_load: 19.12, open: 774.37, short: 677.25
  Unsmoothed RMS: ambient: 130.95, hot_load: 71.28, open: 1341.94, short:
1235.11

```

```

[ ]: min_rms = inf
     for params, rms in rms_per_param.items():
         if rms < min_rms:
             min_rms = rms
             best_params = params
     print("Best set of params: ", best_params)

```

## 1.4 Model Variance

In this section, we look at the variance of the data from each source as a function of frequency, and compare it to a model based on the known input temperature.

**Note: in this case, it does not make sense to do this, as the default fit is too poor.**

## 1.5 MCMC-derived Calibration Fit

In this section, we derive the calibration parameters using MCMC so that we have an estimate of the covariance of the parameters. We can do this using a *model* for the variance, or the empirical variance.

**Note: this should only be done if the initial default fit is reasonable, as it takes a lot longer.**