# Validation of edges-cal using simulated sky signal

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## Motivation

It is reported in Memo 203 that the level of differences in calibration coefficients between the two pipelines remain in the order of $10^{-3}$. To bring down the differences, we identified possible areas where our analysis could be slightly different from those of Alan's. The tests are described in Memo 205, and listed here for brevity.

1. Changing the default `lstsq` matrix-inverse solving method used to solve for the linear parameters to a custom-writting method `_alan_qrd`, which is a port of the C function in Alan's code.
2. Changing the hot-load loss from being applied to the thermistor temperature, to instead be applied to the spectrum (in reverse).
3. Adding a subtraction of a fitted delay to the noise-wave correlated data.
4. Using 8 iterations instead of the default 4.
5. Switching from modelling and smoothing $C_1$ and $C_2$ within the calibration loop to instead only modelling them at the end of the loop.
6. Switching from using a standard polynomial with integer-order terms, to half-integer order terms for $C_1$ and $C_2$ - refer Memo #205 for the definition of the polynomial.
7. Changing the precision at which calibration output is written in Alan's C code, from 6 digits after decimal to 12 digits after decimal.

To quantify the errors in cal-coefficients, for each of these cases, a sensitivity test is done to evaluate the level of residuals due to error in calibration. To do this, we use the following analysis procedure:

1. Simulate a sky signal using a simple power law with fixed spectral index (in this test, $\beta = -2.55$)
2. Decalibrate the sky signal using Alan's calibration co-efficients and antenna S11
3. Recalibrate using cal-coefficients and antenna S11 from `edges-cal`.
4. a difference between the obtained sky signal relative to the input simulated sky signal will show the level of error in calibration.

Figure descriptions:

1. Figure 1 shows the difference between the modelled antenna S11 between the two pipelines.
2. Figure 2 shows the difference between the modelled S11 between the two pipelines for calibration sources.
3. Figure 3 shows the difference between the obtained calibration co-efficients between the two pipelines.
4. Figure 4 shows the effects of each of the test cases described using the decalibration/re-calibration test using cal-coefficients from each pipeline. Note that the biggest effects are from delay subtraction in noise wave calibration and the use of half-integer polynomial terms in the fit for $C_1$ and $C_2$.
5. Figure 5 shows the recalibrated signal, but with different frequency ranges. The frequency range for antenna S11 model for both the pipeline is set to 53-105 MHz but is different in the decalibration and recalibration step by masking 1MHz at a time for each test cases.
6. Figure 6 shows recalibrated signal, but when frequency cuts for antenna S11 models are different in both the pipelines. For C-code, the frequency cut is set to 53-105 MHz, but for `edges-cal`, it reduces by 1 MHz for each test cases. This shows that the difference in frequency cuts for the antenna S11 models between the two pipelines has a significant effect on signal recovery.
7. Figure 7 shows difference in calibration coefficients between `edges-cal` and Alan's C-code, but when the calibration output is saved in two different precision - 6 digits after decimal and 12 digits after decimal. A lower precision file save shows comb structure in the differences, indicating the need to increasing the precision in the file write.

# Conclusion

The two pipelines are now capable of producing the same results, with machine precision (order of 1e-6 or lower), when the all the parameter choices are the same. This memo and Memo #205 both show the plots of differences between the two pipelines at each step of the calibration, such as raw and modeled s11, calibration coefficients. This memo further quantifies the effects of the obtained differences using simulated sky signal. This is done by using Alan's calibration coefficients to decalibrate the sky signal and `edges-cal` results to recalibrate it to recover the signal. The differences are below the noise levels (1 mK), when all the input parameters and the analysis is replicated in the python pipeline. We note however, when there is no delay subtraction in the noise wave calibration, the RMS in the difference between recovered and simulated signal is slightly higher (9 mK), but still below the noise level. We also note that when the number of polynomial terms in $C_1$ and $C_2$ fits is changed, the RMS in the difference between the simulated and recovered sky signal is 104 mK. When the two pipelines model antenna S11 in different frequency cuts, the RMS in the difference between recovered signal and the simulated signal is slightly higher. Updating the C-code to write the calibration outputs to a higher precision (12 digits after the decimal) avoids numerical errors and comb-like structures in the differences.

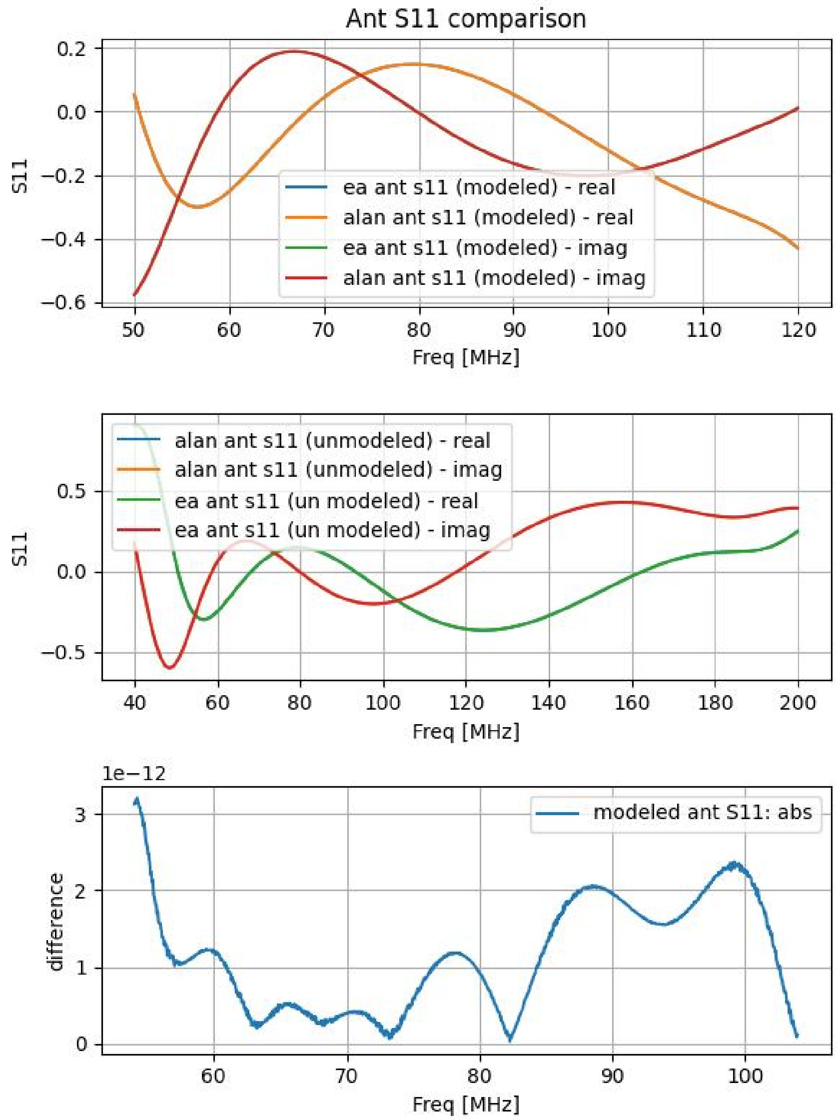


Figure 1: Difference between the modelled antenna S11 obtained from Alan's C-code and `edges-cal`.

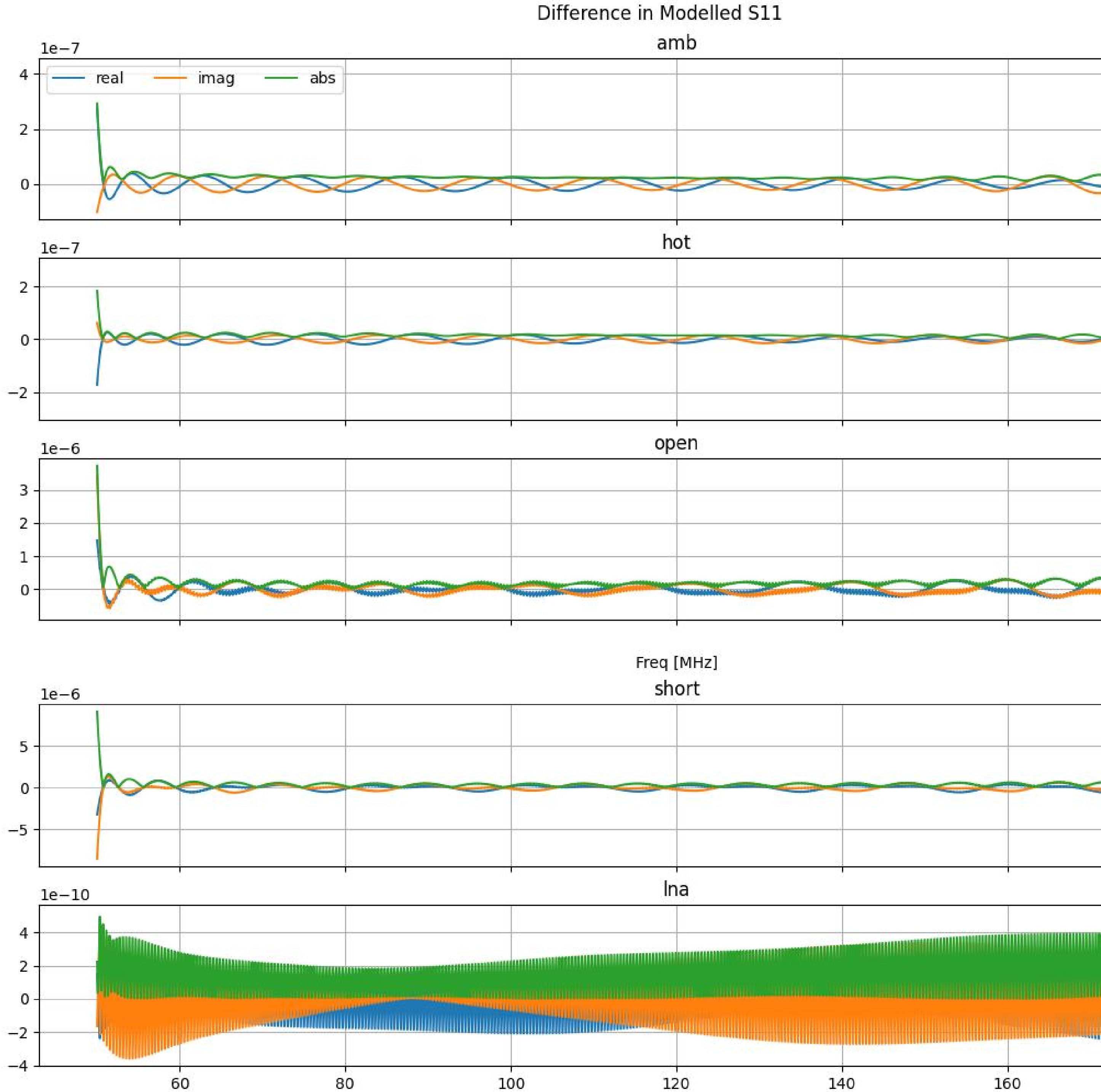


Figure 2: Difference between the modelled S11 obtained from Alan's C-code and `edges-cal`.

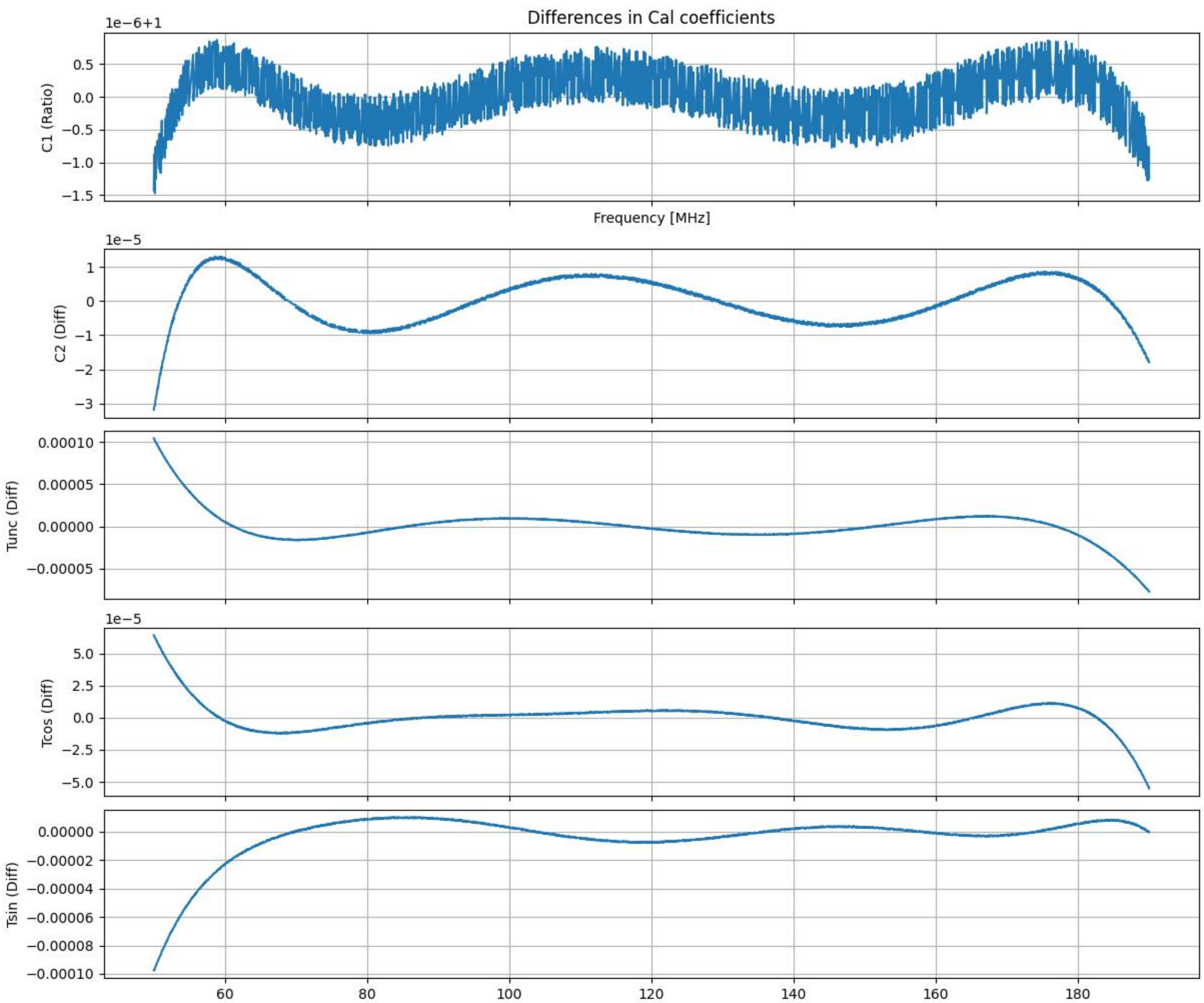


Figure 3: Difference in calibration coefficients obtained from Alan's pipeline and `edges-cal`.

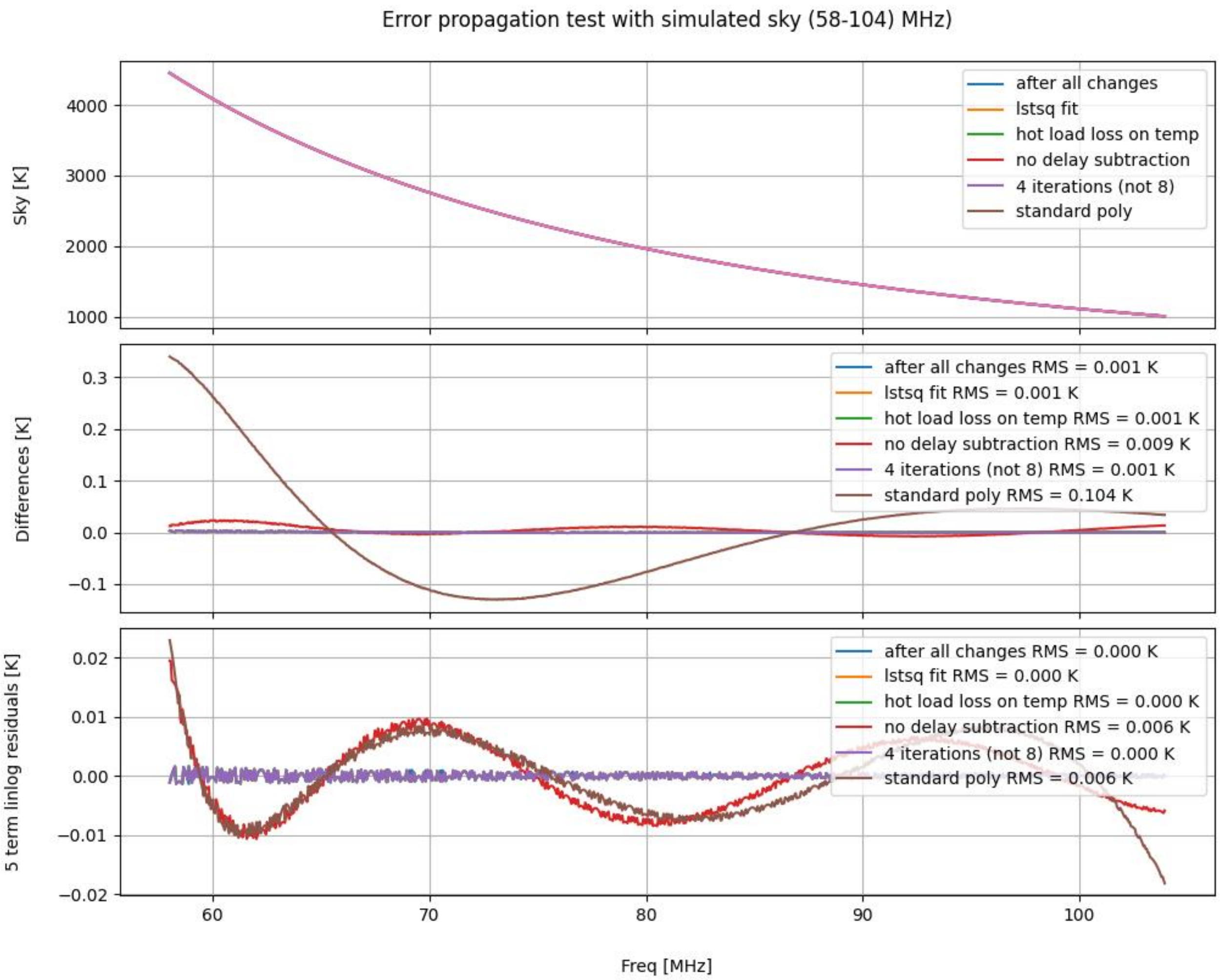


Figure 4: Effects of each of the test cases described using the decalibration/recalibration test using cal-coefficients from each pipeline. Note that the biggest effects are from delay subtraction in noise wave calibration and the use of half-integer polynomial terms in the fit for $C_1$ and $C_2$. *(Top:)* Simulated sky following the power law, and recalibrated sky (obtained after decalibration using Alan's calibration coefficients and recalibration using `edges-cal` calibration coefficients). *(Middle:)* Difference between the obtained signal and the simulated signal for each test case. *(Bottom:)* Residuals with a 5-term linlog model on the recalibrated signal for each of the test cases.

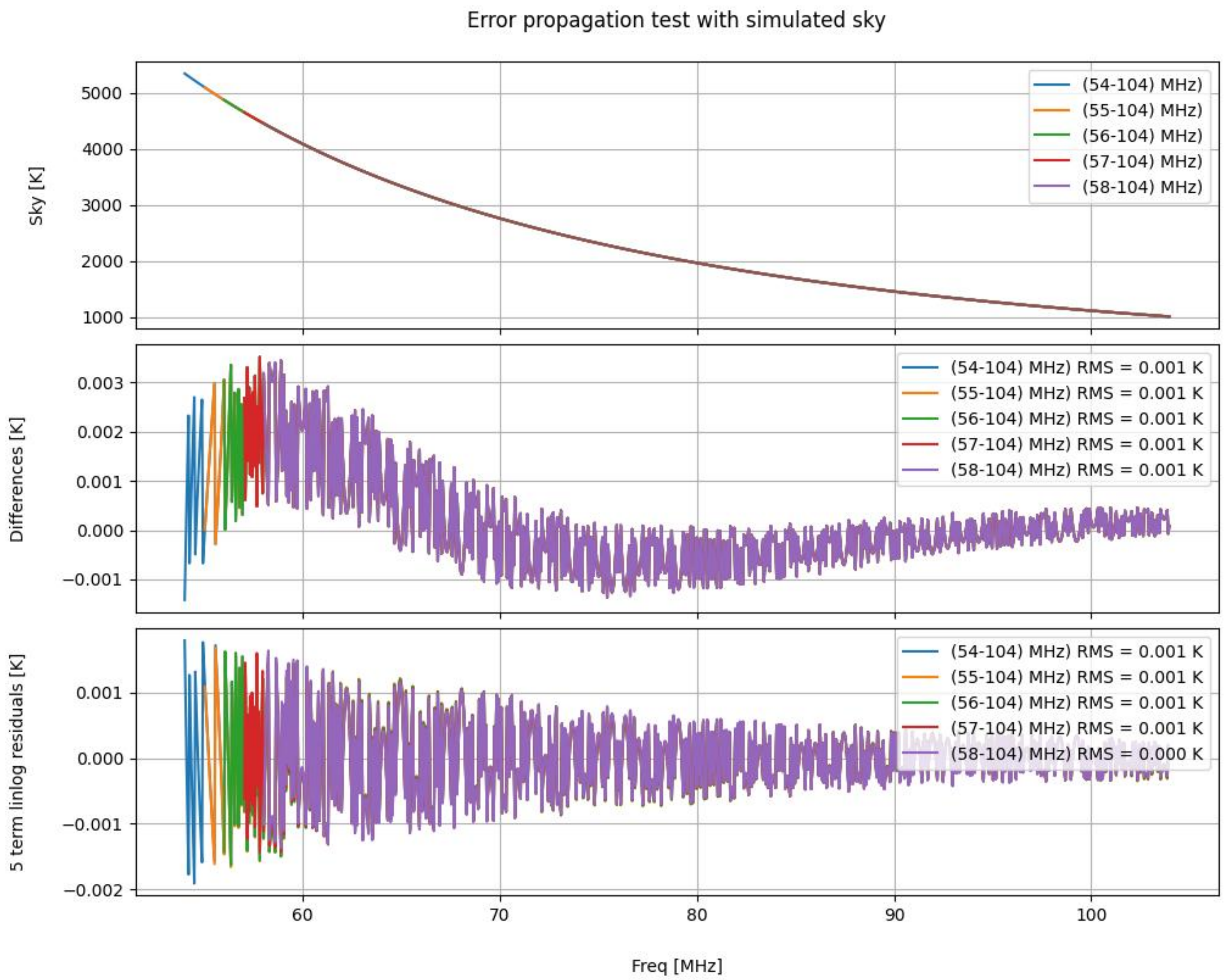


Figure 5: Recalibrated signal, but with different frequency ranges. The frequency range for antenna S11 model for both the pipeline is set to 53-105 MHz but is different in the decalibration and recalibration step by masking 1MHz at a time for each test cases. *(Top:)* Same as Figure 4, but changing the `wfstart/wfstop` in the analysis. Ant S11 for both the pipelines is modeled between 53-105 MHz. However, only a subset of that is used in signal recovery in steps of 1MHz.

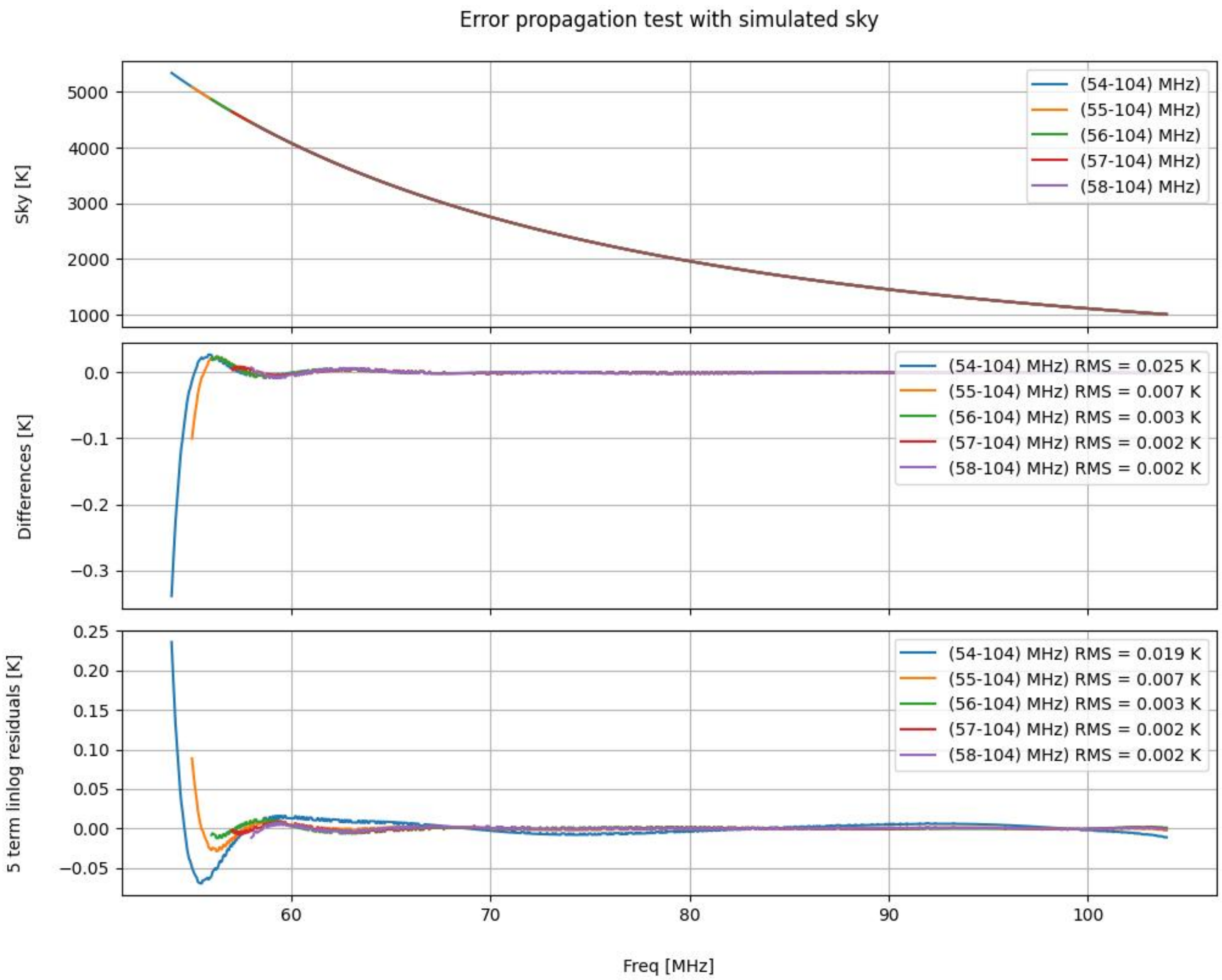


Figure 6: *(Top:)* Same as Figure 4, but changing the `wfstart/wfstop` in the analysis, i.e,. when frequency cuts for antenna S11 models are different in both the pipelines. For C-code, the frequency cut is set to 53-105 MHz, but for `edges-cal`, it reduces by 1 MHz for each test cases. The higher RMS here shows that the difference in frequency cuts for the antenna S11 models between the two pipelines has a significant effect on signal recovery.

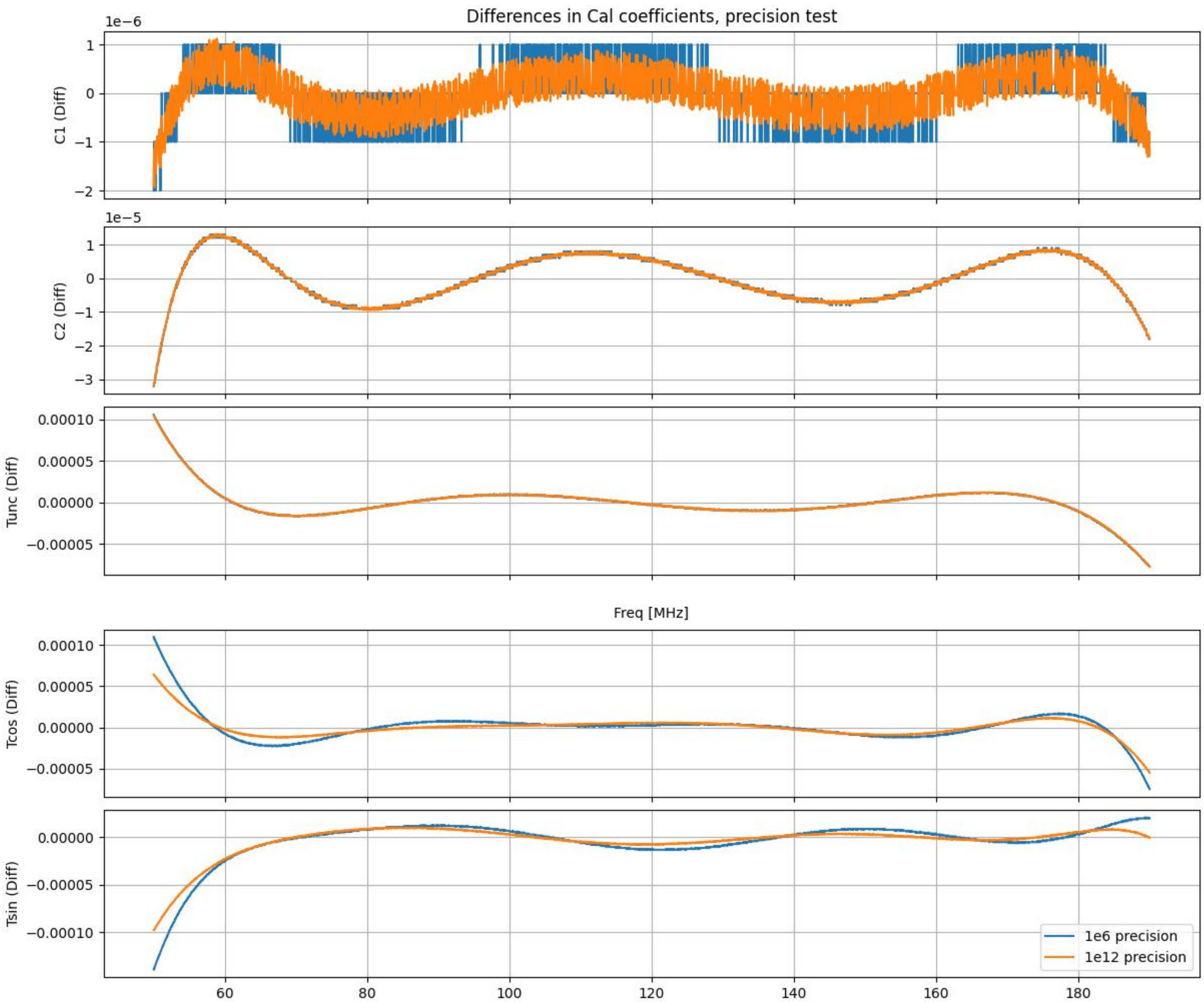


Figure 7: *(Top:)* Difference in calibration coefficients between `edges-cal` and Alan's C-code, but when the calibration output is saved in two different precision - 6 digits after decimal and 12 digits after decimal. A lower precision file save shows comb structure in the differences, indicating the need to increasing the precision in the file write.