Observing Notes for the October 8, 2020 Observations of the Moon

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Here are the observing details for the two sets of observations of the Moon, taken on Sept 11 and Oct 8 with the following. The major differences are in bold:

- For September, we had antennae 1A, 1C, 1F, 1K, 2A, 2H, 4G, 5C.
- For October, we had the same antennae plus 1H and 4J
- The first observation on each night was on the Moon, centered at 1200 MHz with a 900 MHz bandwidth and a frequency resolution of 0.22 MHz.
- The integration time on the Moon was 30 seconds, after which the telescope was moved +20° in Azimuth to a reference position. The telescope then integrated another 30 seconds at the reference position.
- This sequence of on and off Moon observations was repeated **3 times in September and 5 times in October. We increased the number of trials to better parameterize the instabilities observed in the September data.**
- The time between the start of an 'on' and 'off' observation was typically 70 seconds, giving a full cycle time of typically 140 seconds.
- The center frequency was then increased by 350 MHz, and the cycle of 3 or 5 trials were repeated, until the center frequency was 10300 MHz
- **In September, the Moon was setting during the observing session, from ~55° to ~20°, while in October, the Moon was rising from ~20° to ~75°.**
- **We increased the attenuation in the IF system for the October observations by 10 dB. We might expect to see changes in performance between the two data sets if there was compression somewhere in the signal path.**
- The system created files in ASCII of the raw data for each antenna, each polarization, each trial, and each setting of the center frequency.

To process the data:

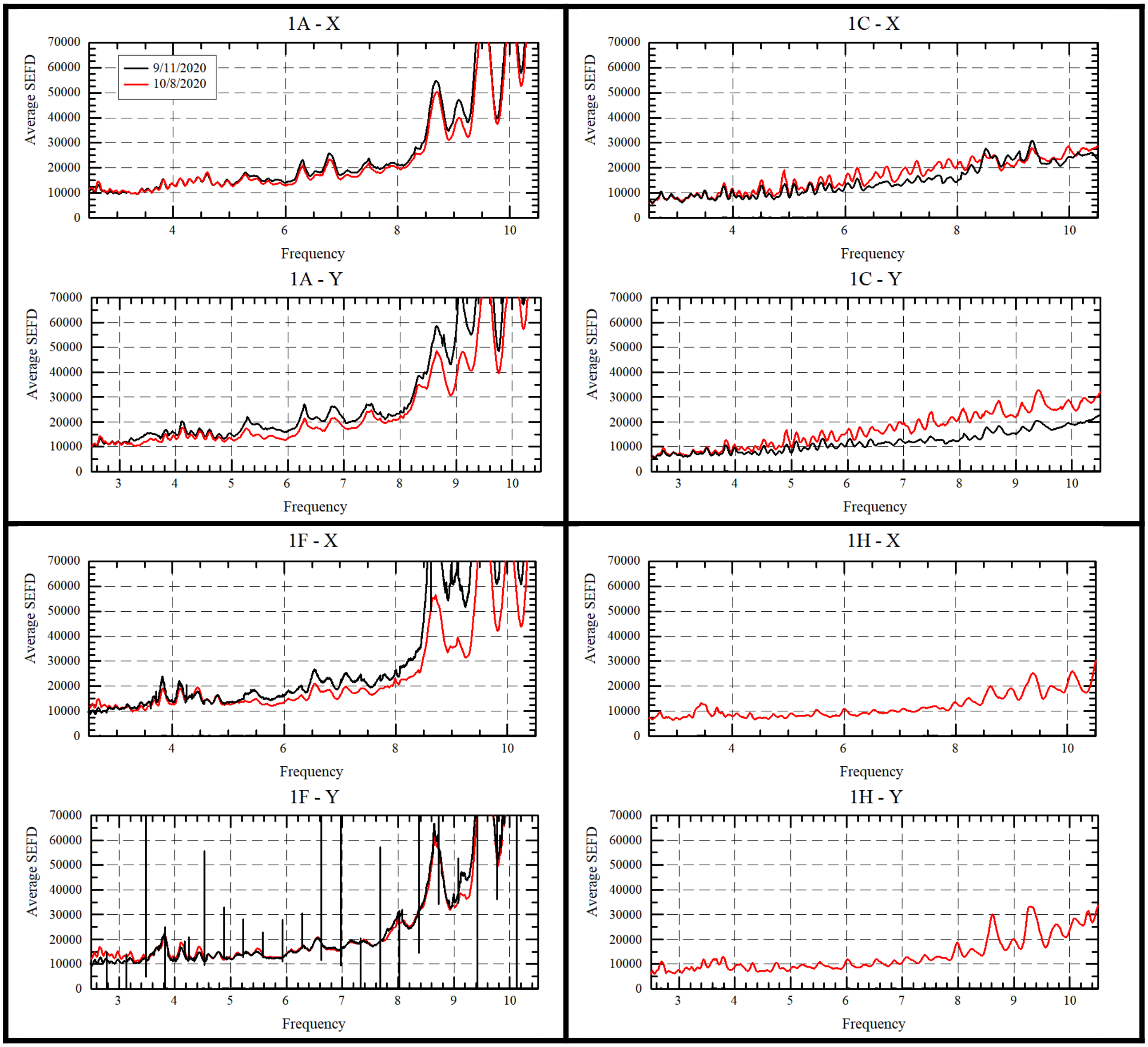
- We processed the center channels of each setting of the central frequency, dropping the frequencies that overlapped between settings of the center frequency. The way in which we dropped overlapped frequencies also eliminated artifacts from the roll offs in gain at the lower and upper ends of the backend's bandpass.
- For each trial, the analysis program created estimates of SEFD, in Jy, for the 'off' Moon position for each antenna and polarizations across the full range of frequencies.

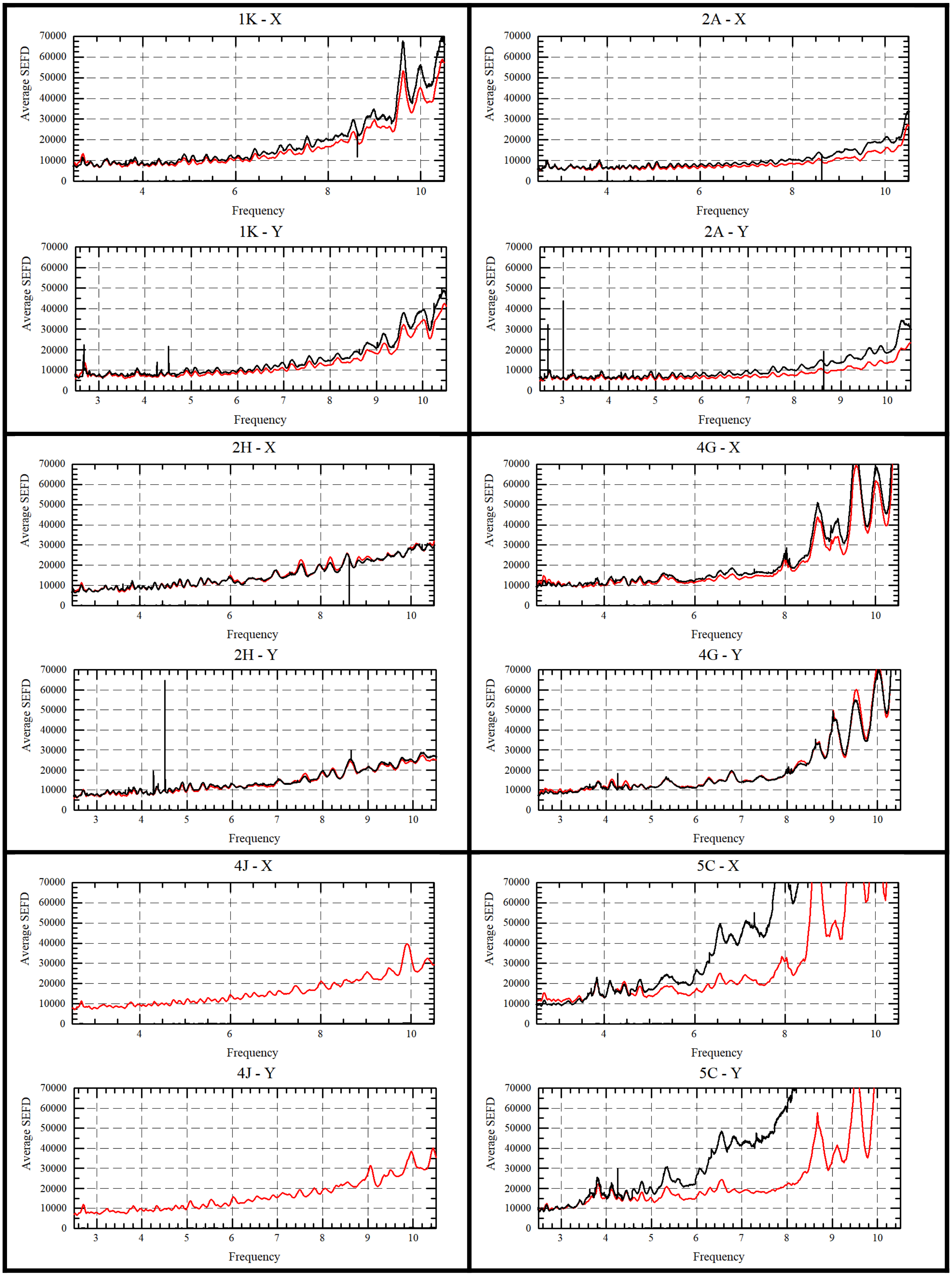
$$SEFD = \frac{P_{Off}}{P_{On} - P_{Off}} \cdot L\left(\nu \cdot R_{Moon}\right) \cdot T_B \cdot \left(\frac{8k}{\pi D^2}\right) \cdot e^{-\tau \cdot csc(elevation)}$$

P_{Off} and P_{On} are the output values from the backend when off and on the Moon, D is the 6.1-meter diameter of the ATA antennae, k is Boltzmann's constant, and τ is the zenith atmospheric opacity (which is frequency and weather dependent, and derived from data provided for each observing session by the National Weather Service). T_B is the Moon's brightness temperature (230 K). L is the conversion factor that takes into consideration how the beam of a clear-aperture antenna (whose FWHM angular size is proportional to the observing frequency, ν) convolves with a disc source of angular radius R and uniform brightness temperature.

Across the full range of possible observing conditions and frequencies, the above approximation to SEFDs have systematic 'scaling' errors that probably will never exceed, in total, 10%. There will also be systematic 'offset' errors that can be many thousands of Jy (see box at the end). Luckily, since the Moon was at approximately the same phase and had approximately the same angular size for the two observing sessions, and the atmospheric opacity and Milky Way contributions were about the same, the September and October data have nearly the same systematic scaling errors and a systematic offset difference of 600 Jy.

The following plots give the estimated SEFDs for each antenna, polarization, and observing session. In all plots, the September data are in black and the October data are in red.





Our conclusions from these are:

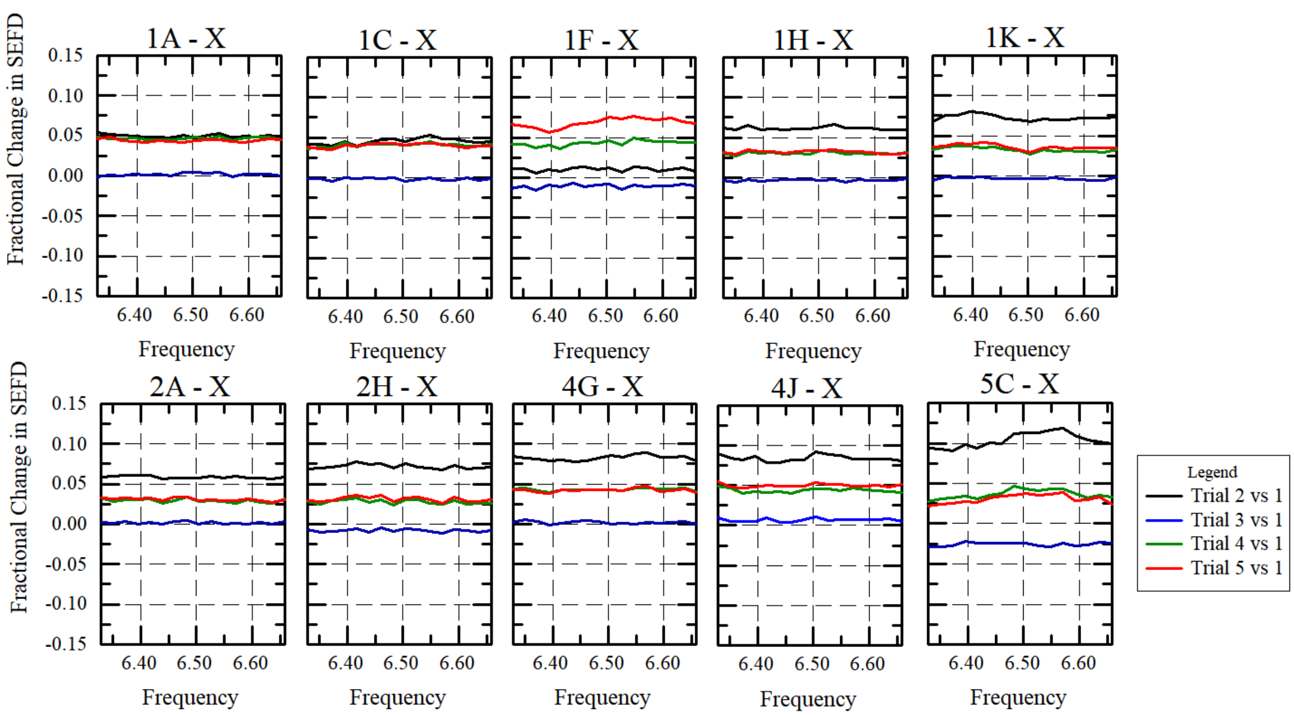
- The rail of spikes in 1F for y-polarization for September, which we attributed to a problem somewhere in the I.F. system, did not occur in October.
- The plots for 1H and 4J do not show data for September since these antennae were not used then.

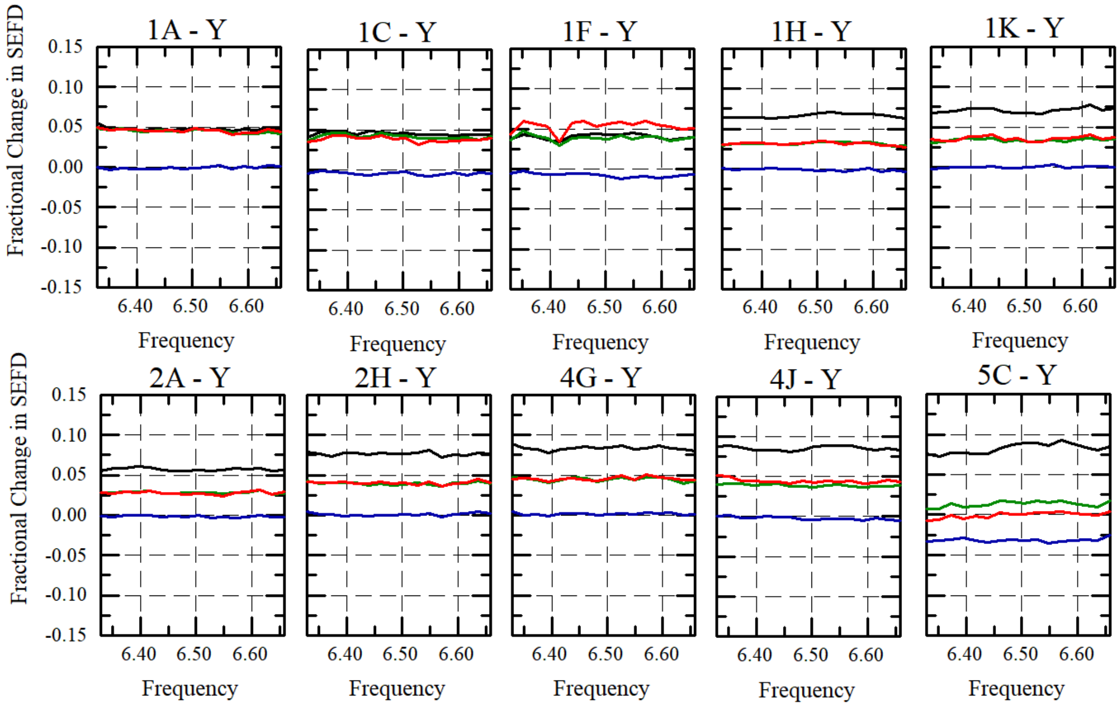
- Of the remaining 16 I.F. channels (8 antennae, 2 polarizations), at least 10 channels showed significant changes in performance between the September and October observing sessions. 1X-Y, 4G-X and 4G-Y have marginal change that exceed the expected 600 Jy scaling offset, while only three (1F-Y, 2H-X, and 2H-Y) had no significant changes.
- The large improvements to 5C-X and 5C-Y may indicate that something else may have happened to that antenna other than the change in attenuation.
- In one of the standard model for compression, P, the detected power, equals $P_{actual}^{1-\gamma}$, where ϒ is non-zero and positive. We can rewrite the first term in the above equation as:

$$\left[\left(\frac{P_{actual,On}}{P_{actual,Off}}\right)^{1-\gamma}-1\right]^{-1}$$

. With this model:
    - If compression is present, the first term in the equation, and thus the derived SEFD will be larger than the actual SEFD. **Mathematically, a reduction in compression (ϒ) should reduce SEFDs. Of the 10 channels that significantly changed, nine had lower SEFDs after the change in attenuation. The exception is 1C-Y, which had a moderate increase in SEFD.**
    - The Moon is much smaller than the beam at low frequencies, but almost fills the beam at high frequencies. Due to beam dilution, the ratio of the actual powers on and off the Moon is at least 10 to 30 times higher at 11 GHz than at 1 GHz. **Since the ratio of powers is higher at higher frequencies, a change in compression (ϒ) mathematically will affect high frequencies significantly more than the lower ones. In all channels where we see a change in SEFD, the higher frequencies always changed the most.**
    - **Since these two trends appear in at least 9 and maybe 13 of the 16 channels observed in both September and October, it is likely that changing the attenuation reduced the compression. This implies that compression has or is occurring in components that are located in the I.F. some place after the attenuators that were altered in October.**

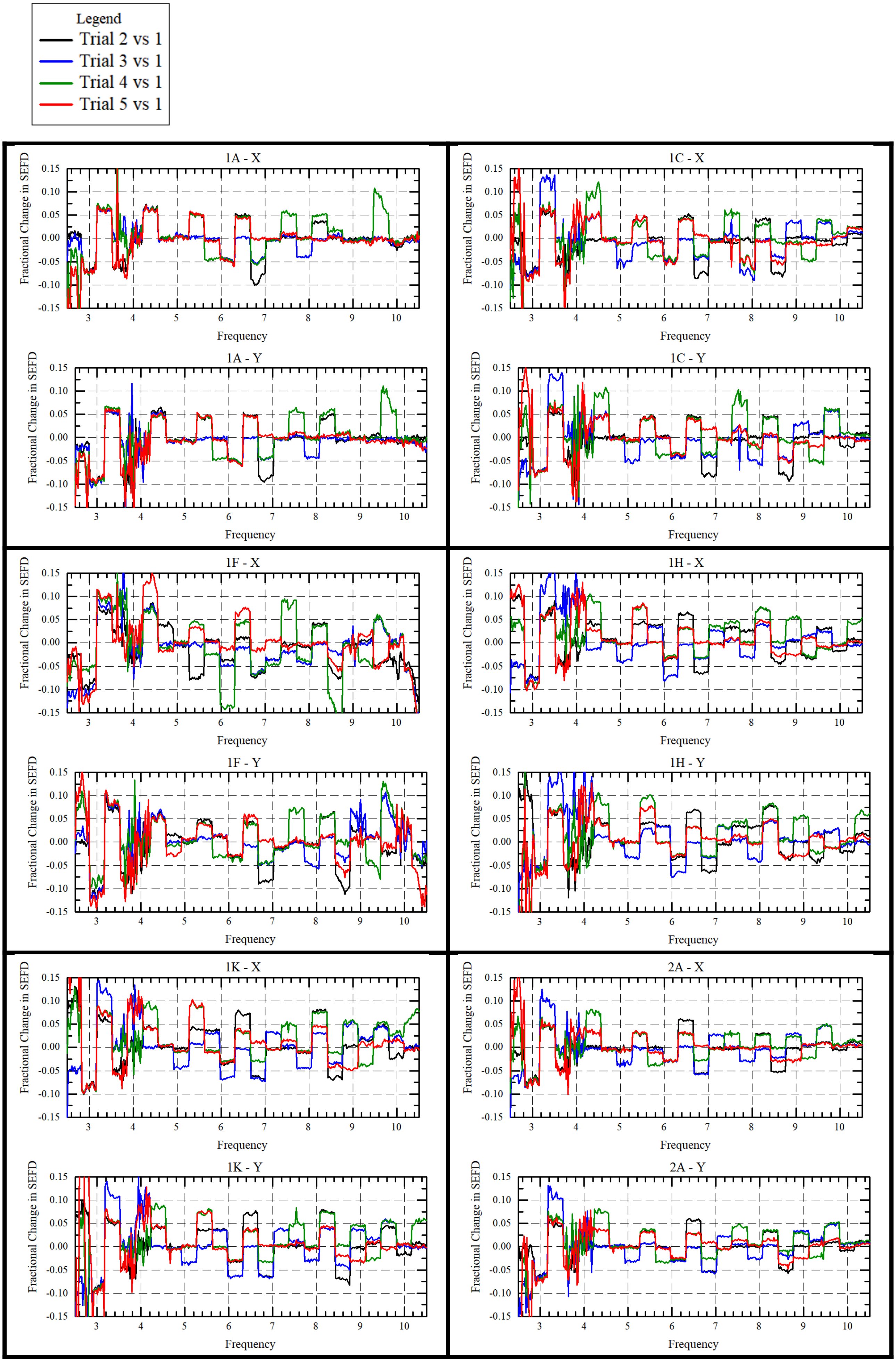
Next, we use the five trials to examine instabilities when observing 'off' of the Moon. We randomly selected a tuning (6.5 GHz) and calculated the fractional change in powers of trials 2, 3, 4, and 5, relative to trial 1. That is, the fractional change in power is $P_n/P_1 - 1$, where n = 2, 3, 4, and 5.

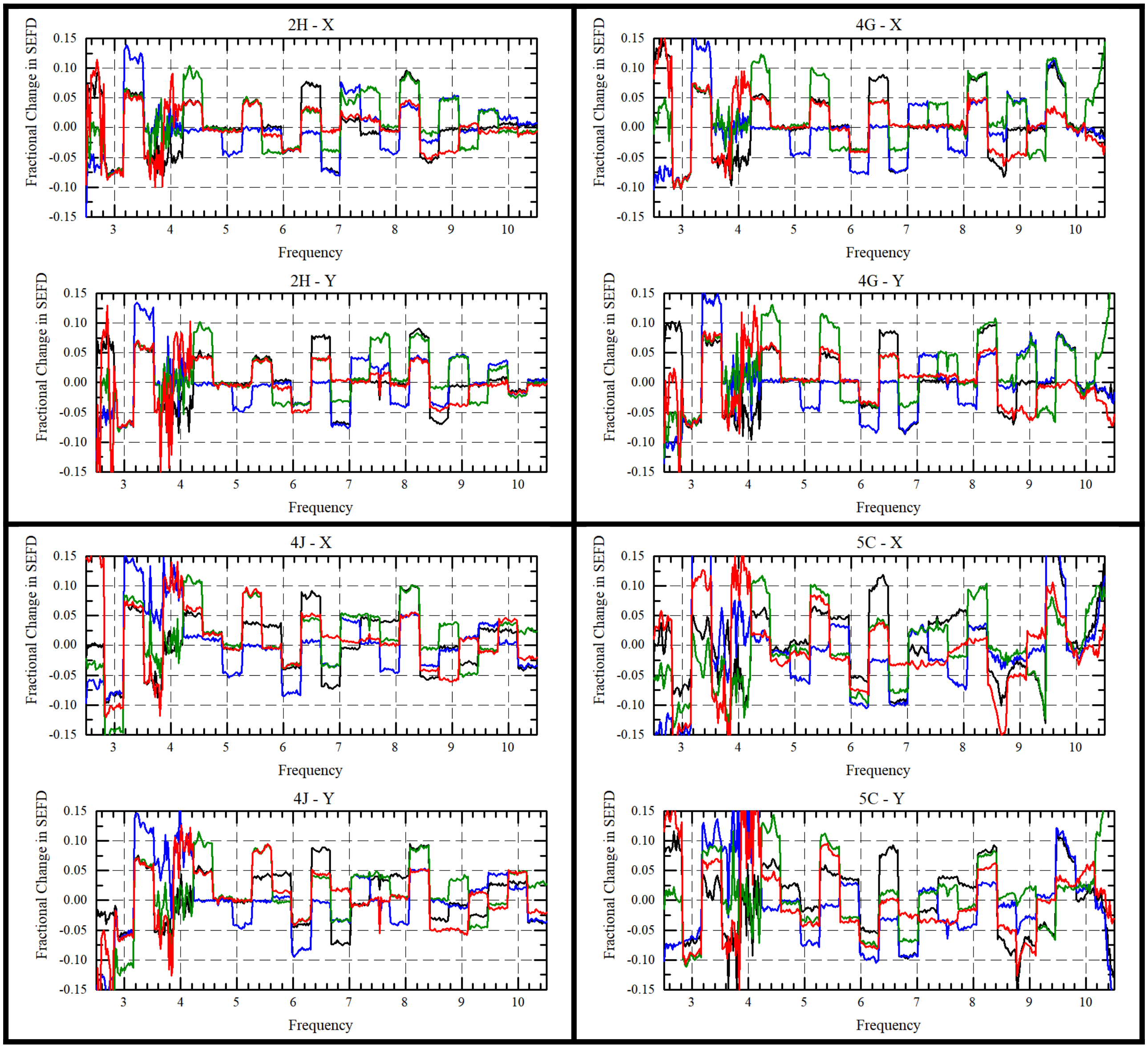




- Since the time span for the 5 trials is about 11 minutes, there is very little change in elevation and Right Ascension and Declination between the trials. It is impossible to generate the magnitude of change in the above plots from the small change in the astronomical sky or Earth's atmosphere.
- Seven antennae (1H, 1K, 2A, 2H, 4G, 4J, and 5C) show almost the same sequence of power changes. Trial 2 had higher detected power than trial 1. Trials 3 and 5 also had higher detected powers than trial 1, but not as high as trial 2. Trial 3 had about the same, or slightly less, power than trial 1.
- 1A has similar power changes to 1C and 1F-Y, but the pattern is different than for 1H, 1K, 2A, 2H, 4G, 4J, and 5C. The power changes for 1F-X are unlike any of the others.

Next we have the fractional power changes for all 10 antennae for all tunings. Since observations across the full band were not done simultaneously but, rather, were split into multiple tunings, one can see steps caused by a change in tuning.


Legend
Trial 2 vs 1
Trial 3 vs 1
Trial 4 vs 1
Trial 5 vs 1
1A - X
1A - Y
1C - X
1C - Y
1F - X
1F - Y
1H - X
1H - Y
1K - X
1K - Y
2A - X
2A - Y
Fractional Change in SEFD
Frequency



- Changes in power, when averaged over 30 seconds, can be as large as 10% over the time span of 140 seconds.
- The September observations show the same magnitude of power changes, but it is less obvious to see patterns with only three trials available.
- One cannot pick out I.F. channels that are significantly more or less stable than others.
- It is unlikely the changes are due to changes in the receiver's contribution to the system temperature as these would affect each antenna differently. We see that the most likely causes of the power changes are:
  - Changes in hardware gain or attenuation that are applied to the whole array or subsets of the array. Is this even possible?
  - Power transmitted by something external to the antennae that is strong enough to alter the gain of all the systems, and possibly their linearity.

Known Sources of Systematic 'Scaling' Errors:
Our assumption that T_B is 230 K, regardless of frequency or lunar phase, is accurate to ~5% according to the Apollo model.

L, which ranges from ~0.02 at 1 GHz to ~1 at 11 GHz, is probably accurate to a few percent since it takes into consideration changes in the Moon's angular size and assumes the rather accurate, standard Bessel beam profile model for an unblocked aperture. There will be a systematic error in L if the feed illumination differs from the assumed -13 dB.

We have not yet taken into consideration (a) the brightness of the Milky Way in the 'off' Moon observation, and (b) the frequency-dependent contributions of the CMB and Milky Way from the 'on' position. As the beam goes from being larger than the Moon at low frequencies to almost the diameter of the Moon at high, the foreground Moon covers more of the background radiation from the CMB and Milky Way.

Known Sources of Systematic 'Offset' Errors:
SEFDs are the sum of the contributions from the electronics, spillover, atmosphere, and astronomical sky. For example, SEFDs will be larger when observing a position close to the plane of the Milky Way, when observing low elevations, and when observing under rain or cloudy skies. These variable components produce variable systematic offsets in the values for SEFD that can be as large as 10,000 Jy for the ATA dishes. Thus, one needs to estimate these offset values when comparing two sets of observations made under different observing conditions.

Although we have not yet adjusted SEFDs for systematic errors, we can estimate the changes they would produce which will allow us to compare the results from the two observing sessions. The left panel below shows, as a function of frequency for the two observing sessions, the values of the scaling factor L, the observed elevations, and the atmospheric opacity and attenuation. In the right panel, the top two graphs show for the two observing sessions the contributions to T_{sys} of the various components. In the bottom graph on the right, we have assumed an aperture efficiency of 0.5 to convert the total Tsys contributions to the total SEFD contributions. The difference in the contributions from the Milky Way, due to differences in astronomical positions, dominates below 2 GHz while the difference in atmospheric contributions, due to difference in observing elevations, dominates above 6 GHz. We should expect the September SEFDs to be 600 Jy higher than the October SEFDs at the higher frequencies. Although the difference is negligible for the observations discussed here, in many cases, the difference will be thousands of Jy.