Beam Switching

Tom Kuiper

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Abstract

This is a tentative analysis of beam switching based on data for DSS-63, pending the data for DSS-43.

Differencing the signals from two feeds can remove the effect of a fluctuating atmospheric brightness temperature. Any gain difference between the two signal paths, however, will register as an apparent continuum with the spectral signature of the gain difference.

Switching the source from one feed to the other and combining those spectra removes this undesirable effect, but only to the extent that the gain is stable between the two measurements.

Differences in gain between the two paths can be reduced by averaging them, alternating the receivers with respect to the front end channels.

Normalized spectra are commonly used in spectral line reduction software. They may not be the best for canceling baseline effects, though.

1 Raw Spectra

1.1 Feed Differencing

With feed 1 pointing at the source, the powers registered by receivers A and B and their difference are

$$\begin{aligned} P_A &= G_1 G_A (T_{rec} + T_{sky} + T_{src}) \\ P_B &= G_2 G_B (T_{rec} + T_{sky}) \\ P_1 &= P_A - P_B \\ &= G_1 G_A T_{src} + (G_1 G_A - G_2 G_B)(T_{rec} + T_{sky}) \end{aligned} \quad (1)$$

where G_1 and G_2 are the time-averaged gains of the amplifiers of the front end channels, and G_A and G_B are the time-averaged gains of receiver A and receiver B. T_{sky} is the same for both feeds so it cancels even though it fluctuates, at least to the extent that $G_1 G_A = G_2 G_B$.

This procedure is equivalent to *chopping* except that different signal paths are used to measure the source and the reference. To the extent that $G_1 G_A \neq G_2 G_B$, there is incomplete cancellation and the spectrum baseline will have the spectral signature of this difference. Figure 1 shows the gains of the cryogenic K-band amplifiers on DSS-63. Taking the data for DSS-43, the

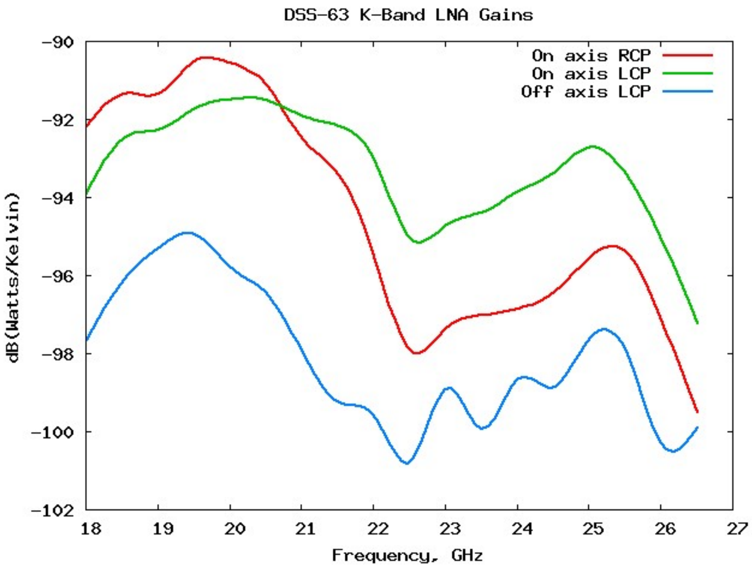

Figure 1: Gains of the cryogenic K-band amplifiers on DSS-63. (Data provided by Manuel Franco.)

LCP channels for both DSS-63 "on-axis" feeds differ by about 5 dB. Thus, the difference in the power between the two channels si about of factor of 3, which means that the difference spectrum will have an apparent continuum of twice the off-axis power or 2/3 of the on-axis power, with the difference of spectral signatures of the two channels.

There is considerable variation with frequency. Even if 4.9 dB of attenuation were inserted in the LCP path, Figure 2 shows that there would be differences as large as 2 dB (-47 to + 58%).

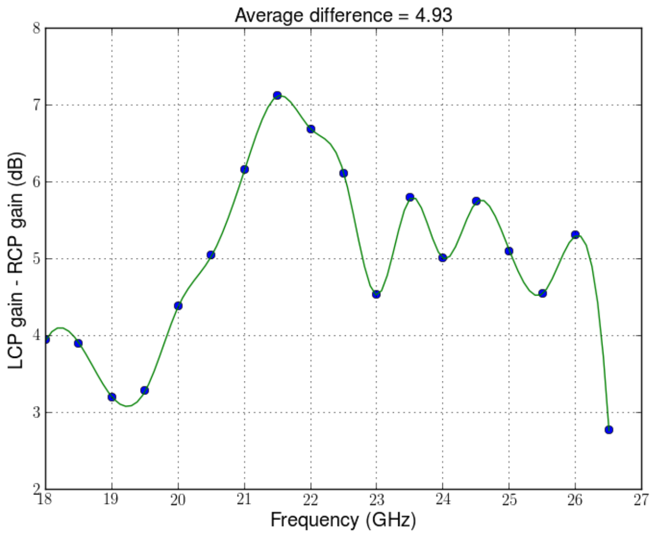

Figure 2: Difference in gain between the K-band LCP "on-axis" and "off-axis" feeds.

Also, if the source emission has a continuum as well as spectral lines, the continuum will have the false spectral signature of $(G_1G_A - G_2G_B)$.

1.2 Beam Switching

With feed 2 pointing at the source,

$$\begin{aligned}
P_A &= G_1G_A(T_{rec} + T_{sky}) \\
P_B &= G_2G_B(T_{rec} + T_{sky} + T_{src}) \\
P_2 &= P_B - P_A \\
&= G_2G_BT_{src} + (G_2G_B - G_1G_A)(T_{rec} + T_{sky})
\end{aligned}$$

This should have the same baseline spectral signature as P_1, but inverted, if the gains are stable during the measurements of P_1 and P_2.

Adding the two measurements cancels the baselines.

$$\begin{aligned}
2P_{src} &= P_1 + P_2 \\
&= (G_1G_A + G_2G_B)T_{src} \qquad (2)
\end{aligned}$$

To the extent that the gains are not stable, the cancellation is incomplete and will result in a spectrally varying pseudo-continuum or "bad baseline".

This is equivalent to telescope *nodding* although, since the two feeds are almost horizontal, perhaps *wagging* would be a better term.

1.3 Feed Switching

With the receivers switched with respect to the feeds and feed 2 pointing at the source,

$$\begin{aligned} P_A &= G_2 G_A (T_{rec} + T_{sky} + T_{src}) \\ P_B &= G_1 G_B (T_{rec} + T_{sky}) \\ P_1 &= P_A - P_B \\ &= G_2 G_A T_{src} + (G_2 G_A - G_1 G_B)(T_{rec} + T_{sky}) \end{aligned}$$

and with the feed 2 pointing at the source,

$$\begin{aligned} P_A &= G_2 G_A (T_{rec} + T_{sky}) \\ P_B &= G_1 G_B (T_{rec} + T_{sky} + T_{src}) \\ P_2 &= P_A - P_B \\ &= -G_1 G_B T_{src} + (G_2 G_A - G_1 G_B)(T_{rec} + T_{sky}) \end{aligned}$$

so that

$$\begin{aligned} 2P_{src} &= P_1 - P_2 \\ &= (G_2 G_A + G_1 G_B) T_{src} \end{aligned} \tag{3}$$

Adding equations 2 and 3 we get

$$\begin{aligned} 4P_{src} &= (G_1 G_A + G_2 G_B + G_2 G_A + G_1 G_B) T_{src} \\ &= (G_1 + G_2)(G_A + G_B) T_{src} \end{aligned} \tag{4}$$

In this way, any differences between the paths are averaged and the baseline greatly improved.

1.4 Gain Non-linearity

2 Normalized Spectra

Normalized spectra are commonly use in spectral line reduction software. They may not be the best for canceling baseline effects, though.

2.1 Feed Differencing

When normalizing spectra, equation 1 becomes

$$\begin{aligned} S_1 &= \frac{P_A}{P_B} - 1 \\ &= \frac{G_1 G_A}{G_2 G_B}\left[1 + \frac{T_{src}}{(T_{rec} + T_{sky})}\right] - 1 \end{aligned}$$

2.2 Beam Switching

The normalized version of equation 2 is

$$\begin{aligned} S_2 &= \frac{P_B}{P_A} - 1 \\ &= \frac{G_2 G_B}{G_1 G_A}\left[1 + \frac{T_{src}}{(T_{rec} + T_{sky})}\right] - 1 \end{aligned}$$

Adding, one gets

$$2S_{src} = \left(\frac{G_1 G_A}{G_2 G_B} + \frac{G_2 G_B}{G_1 G_A}\right)\left[1 + \frac{T_{src}}{(T_{rec} + T_{sky})}\right] - 2 \tag{5}$$

The baseline variations do not quite cancel in this way, although if one assumes that $G_1 G_A \simeq G_2 G_B$ so that we can consider $G_2 = G_1 + \Delta G_1$ and $G_B = G_A + \Delta G_A$, then one can see that it is approximately true. However, in the light of Figure 1, this may not be the best assumption.

2.3 Feed Switching

If we take another set of measurements with the feeds (or receivers) swapped one gets

$$\begin{aligned} 4S_{src} &= \left(\frac{G_1 G_A}{G_2 G_B} + \frac{G_2 G_B}{G_1 G_A} + \frac{G_1 G_B}{G_2 G_A} + \frac{G_2 G_A}{G_1 G_B}\right)\left[1 + \frac{T_{src}}{(T_{rec} + T_{sky})}\right] - 4 \\ &= \left(\frac{G_1}{G_2}\left(\frac{G_A}{G_B} + \frac{G_B}{G_A}\right) + \frac{G_2}{G_1}\left(\frac{G_B}{G_A} + \frac{G_A}{G_B}\right)\right]\left[1 + \frac{T_{src}}{(T_{rec} + T_{sky})}\right] - 4 \\ &= \left(\frac{G_1}{G_2} + \frac{G_2}{G_1}\right)\left(\frac{G_A}{G_B} + \frac{G_B}{G_A}\right)\left[1 + \frac{T_{src}}{(T_{rec} + T_{sky})}\right] - 4 \end{aligned}$$

in which the baseline approximately cancels if $P_A \simeq P_B$ and $P_1 \simeq P_2$. The latter, at least, is probably true.