Ka-band correlation receiver offset and stability notes

A. Harris 11/30/06

1 Ideal correlation radiometry

The ideal continuum correlation radiometer has a correlator output of

$$u = \alpha\beta\left(T_X - T_Y\right)\sqrt{G_A G_B}$$

where T is the input temperature in front of the two input hybrid inputs X and Y, G is the power gain of the set of amplifiers after the input hybrid, and α and β are the hybrid's voltage transmission coefficients. T_X and T_Y would also be the temperatures at the two input horns in the ideal case. The fundamental idea behind correlation radiometry is that hen $T_X = T_Y$, as will be the case when observing faint sources, the output is zero, so small amplifier gain fluctuations do not affect the correlated output.

2 Nonideal performance characteristics of the Ka/Zpectrometer system

The nonideal performance we see with the Ka/Zpectrometer system is:

- Nonzero correlator outputs are present when both horns are on the same temperature load. The largest outputs are not at zero lag (total power), but are at low lags. These represent long-wave structure in the spectral baselines. The amplitudes of the nonzero terms are up to 20 K effective temperature.
- The nonzero terms vary with time, with typical transition from white noise to drift at 3 seconds in the low lags. The fractional amplitude change is a few percent over minutes. High lags are close to zero amplitude and have stability times beyond 50 seconds. The 3 second timescale is present in the lab and on the telescope looking at the sky.
- The nonzero terms are sensitive to the temperature input to both horns: that is, it is possible to measure a Y-factor with ambient and cold loads that cover both horns. The Y-factors correspond to radiation temperatures between 300 and 17 K.

These three properties for the nonzero lags show that the system is not operating close to the ideal performance for a correlation receiver; amplifier gain fluctuations modulate the nonzero outputs to produce nonideal noise.

3 Structure in the cross-correlation functions

We see three sets of structure in the cross-correlation functions. In order of largest to smallest, we see

- First order: As described above in the list of nonideal performance.
- Second order: The first set of lab measurements revealed lower level offsets present in all lags. We resolved this problem by phase switching in both amplifier chains: the difference in gains for the two phase switches is considerably flatter with frequency than the absolute gain with frequency.

- Third order: We see some sign of structure that does not correspond to the first-order structure, but it is still buried in the larger structure. Some contributions here may come from reflected amplifier noise and other high-order effects.

4 Things we can rule out as causes of the large (first-order) structure

It is very likely that the structure we see is due to differential loss in the circuit before the first hybrid. Before making a careful analysis of this, we can rule out the following effects:

- Transmission imbalance in the hybrid has no effect in a practical system.
- Delay differences between the horns and the first hybrid has no effect in a practical system.
- Cross-coupling between hybrid inputs can have a slight gain effect but cannot cause non-zero outputs.
- Cross-coupling between hybrid outputs has no effect to high order.
- Phase mismatches between the amplifier chains affects gain but cannot cause non-zero outputs.
- Phase mismatches between the amplifier chains affects gain but cannot cause non-zero outputs.
- Delay mismatches between the amplifier chain outputs affects gain but cannot cause non-zero outputs.
- Gain mismatches in the amplifier chains (this includes phase switches) cannot cause non-zero outputs.
- Instabilities anywhere behind the splitters in the four-channel downconverter. There are two 2-18 GHz amplifiers in the downconverter that could be unstable, but the remainder of the system gain is in the Ka-band receiver.

5 The likely cause of the large (first-order) structure

A differential gain difference between the inputs to the first hybrid, combined with amplifier uncertainty (probably from the cold amplifiers) can explain the effects we measure. Including loss in the equation for the correlator output yields

$$u = \alpha\beta\left[\left(T_X G_X - T_Y G_Y\right) + \left(T_{LX} G_X - T_{LY} G_Y\right)\right]\sqrt{G_A G_B}$$

where G_X and G_Y are the gains (1/loss) of the circuit at the hybrid's inputs and T_{LX} and T_{LY} are the effective temperatures associated with these losses. When both horns are terminated at the same temperature, $T_X = T_Y = T_{in}$ and the losses are resistive at temperature T_L then the output is

$$u = \alpha\beta\left[\left(G_X - G_Y\right)\left(T_{in} - T_L\right)\right]\sqrt{G_A G_B} \quad ,$$

Where T_L is the Y-factor temperature of the receiver with the same load temperature into both horns. This result shows that a nonzero T_{in} or T_L produce a nonzero correlator output, the effect that we see. Fluctuations in G_A or G_B then have a nonzero term to multiply and will appear as a fluctuating correlator output u.

We measure the following Y-factor temperatures:

Slot 1 (up to 40 GHz)	36 K
Slot 2	300 K
Slot 3	24 K
Slot 4 (down to 26 GHz)	17 K

The change of temperature with frequency suggests that the loss is not purely resistive, so the radiation temperature cannot be derived from loss and ambient temperature. (As a note: an ideal receiver would have an infinite Y-factor temperature since the output should not change if both inputs are terminated at the same temperature.)

We can make an estimate of the loss by making some approximations. First, find the factor $\alpha\beta\sqrt{G_A G_B}$ by assuming that the receiver does work as an ideal correlation receiver when the input imbalance is large: 300 K for one horn, 80 K for the other. Then

$$10^4 \text{ cts } = \alpha\beta\sqrt{G_A G_B}\left(200 \text{ K}\right) \quad .$$

From lab measurements or about 50 cts/K. Now assume that $G_X \approx G_Y \approx 1$, a low-loss case, and assume that the T_L term can be ignored, setting a lower limit on the loss, for

$$u = \alpha\beta\left[\left(1 - \frac{G_Y}{G_X}\right)T_{in}\right]\sqrt{G_A G_B} \quad .$$

For T_{in} = 290 K and G_Y/G_X = 0.2 dB, u ~ 700 cts with the 50 cts/K conversion factor. This is close to our larger measured nonzero output levels. Although this is not exact, it is a plausibility calculation that shows that a differential loss of 0.1 to 0.2 dB can explain the effects we see. It is possible that this loss comes from the difference in waveguide runs or other components between the horns and the two inputs.