Gain and Amplitude Calibration Using Interferometery

Jim Gibson and Jack Welch,
Radio Astronomy Laboratory,
UC Berkekey

September 15, 2005

1 The Single Antenna System

Figure 1 shows the basic single antenna system with antenna effective area A_i, amplifier with system temperature T_{sys_i} and gain k_i, including a-d converter and output autocorrelator. With an input antenna temperature, T_{ant_i}, the output is O_i.

$$O_i = k_i(T_{ant_i} + T_{sys_i}) \tag{1}$$

With two different known input antenna temperatures, T_{i1} and T_{i2}, we get two outputs. O_{1i} and O_{2i}. Their ratio, $Y_i = O_{2i}/O_{1i}$, gives the system temperature.

$$T_{sys_i} = \frac{Y_i T_{1i} - T_{2i}}{1 - Y_i} \tag{2}$$

The two measurements also give the amplifier scale factor,

$$k_i = \frac{O_{2i}}{T_{2i} + T_{sys_i}} \tag{3}$$

If antenna i is pointed toward a point source of flux S, the antenna temperature is $T_{ant_i} = (A_i/k_b)$ S, and the output is $O_i = k_i[T_{sys_i} + (A_i/k_b)S]$, Where k_b is Boltzmann's constant, and A_i is the antenna effective area.

2 Interferometric Gain Calibration

In the array of antennas there is one small horn whose gain can be known to an accuracy of $\leq 1\%$. The goal is to transfer this gain to the other antennas, keeping that accuracy. All the system temperatures, T_{sys_i}, and amplifier gains, k_i, must be measured as described above, or in some equivalent manner. Here we assume that the amplifier passbands are identical and all the delays have been removed. It is further assumed that the interferometer correlator can provide both auto and cross correlations, so that the correlator gain factor is just the geometric mean of the individual autocorrelation gains. $k_{ij} = \sqrt{k_i * k_j}$ is known from the single antenna measurements above. Figure 2 shows the block diagram for a pair of antennas in the array. The output when the pair is pointed at a point source of flux S is

$$O_{ij} = S\sqrt{A_i A_j} k_{ij} \tag{4}$$

To transfer the antenna gains we form the following rations.

$$\frac{O_{ki}O_{kj}}{O_{ij}} = \frac{\sqrt{A_k A_i} k_{ki} S \sqrt{A_k A_j} k_{kj} S}{\sqrt{A_i A_j} k_{ij} S} = A_k \frac{k_{ki} k_{kj}}{k_{ij}} S \tag{5}$$

The main point about getting the single antenna flux of the source is that we use the crosscorrelations between antennas to get them, so that the result depends on the geometric means of the gains of the antennas in the pairs. The gain of the standard horn is typically 40 dB less than that of the other antennas in the array. If we were to measure the signal of the astronomical source directly with the horn antenna by itself, it would be too weak relative to the receiver noise to measure. In the crosscorrelation between the horn and one of the other array antennas, the signal is typically 20 dB greater, and it can be measured with good accuracy for strong sources such as the planets.

Let the standard gain horn be the k = 0 antenna. Then, for example, we can get a measurement of the point source flux from the following ratio.

$$\frac{O_{01}O_{02}}{O_{12}} = A_0 \frac{k_{01}k_{02}}{k_{12}} S \tag{6}$$

Since A_0 is accurately known, we get an accurate flux for S from the above ratio. Now we can obtain the gain of another antenna from another ratio of visibilities. For example,

$$\frac{O_{12}O_{13}}{O_{23}} = A_1 \frac{k_{12}k_{13}}{k_{23}} S \tag{7}$$

With S known, we get gain A_1 from this measurement. With the corresponding other ratios we get the gains of all the antennas. With care, we should get the gains of all the antennas with accuracies of the order of 1%. Another advantage of using the interferometer pairs for total flux measurements of the point source is that front-end drifts of single antennas are avoided.

Figure 1

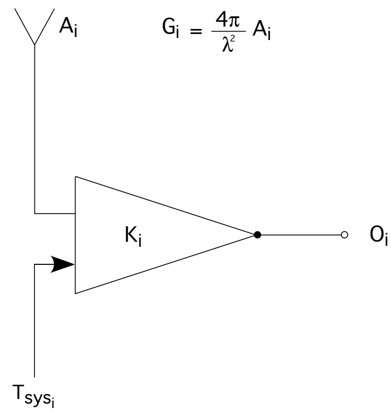

Figure 2