The receiver baseline of the 21-cm line receiver as a function of frequency for the 300-foot telescope.

2. Further measurements

by G. Westerhout and H. U. Wendlandt
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The measurements of the frequency-dependent baseline at 21 cm reported in paper 1 were continued in the summers of 1971 and 1972 as a standard procedure in the observations of the Maryland-Green Bank 21-cm line survey. Twice a day, around 8^h and $17^h\ 30^m$ LST, approximately 45 minutes were spent measuring 21-cm line profiles at high galactic latitudes (stationary telescope at declinations 0° and 60°) using total bandwidths of 2.5 and 5 MHz. The receiver system used was the same 4-feed front-end used during the 1969-70 period, but the autocorrelation receiver was the Mark III receiver rather than the Mark II used during the earlier period. Moreover, in between the two periods, in Fall 1970, the 300-foot telescope was resurfaced, and the moving feed assembly, used for low-frequencies was installed and in place (although not used) during the measurements reported here.

The same method was used: line profiles were integrated over 5-minute periods and plotted on the Charlottesville CalComp plotter. Only feeds 3 and 4 of the four-feed system were used. The following combinations of feed and autocorrelator were employed:

Feed 4: 5 MHz bandwidth, 384 channels
5 MHz bandwidth, 192 channels
2.5 MHz bandwidth, 192 channels

Feed 3: 5 MHz bandwidth, 192 channels
2.5 MHz bandwidth, 192 channels

Except for September 1972, (see below) all measurements were made with the feed rotation angle 0, and twice a day at both 0° and 60° declination.

Data reduction: Each feed and each observing period was treated separately. A least-squares straight-line baseline was fitted to the profiles, omitting a region ± 400 kHz from the laboratory frequency of the line, on which the data was centered. The 2.5 and the 5 MHz data were collected together to arrive at one single baseline for each feed and each observing period. Finally, in

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*) Internal report, Astronomy Program
University of Maryland
College Park, Maryland 20742

September 1972, measurements were not only made at two different declinations, but at each declination at four different rotation angles of the feed (0°, -30°, -75° and -120°) and these were collected together separately for each feed and each rotation angle.

Results: For the two weeks during Summer 1971, it was impossible to detect any deviations from a straight-line baseline greater than ± 0.1K. There were some indications of a sine-wave pattern with amplitude of perhaps 0.05K and period of the order of 1 MHz, but they disappeared largely in the noise and consequently it was impossible to draw any conclusions about stability of the pattern.

For the three weeks during Summer 1972, an extremely stable baseline was found. Both for feed 3 and feed 4 the baseline could be approximated perfectly by a sine wave of period 800 kHz and amplitude 0.10K and 0.20K, respectively. The phases of the sine waves were different. If f is expressed in kHz measured from the laboratory frequency, we can express the baseline deviations from a straight line as:

Feed 3: $T_{base} = 0.10 \sin[-2\pi(f+420)/800]$ K.

Feed 4: $T_{base} = 0.20 \sin[-2\pi(f+17)/800]$ K.

The r.m.s. error in the period is estimated to be ± 20 kHz, the error in the phase ± 40 kHz and the error in the amplitude ± 0.02K. For each feed, no systematic effects could be detected as a function of bandwidth, number of channels, declination, or time.

For the three weeks in September 1972, the same stable situation was observed, but phases and amplitudes were entirely different:

Feed 3: $T_{base} = 0.11 \sin[-2\pi(f+160)/800]$ K.

Feed 4: Amplitude less than 0.08K, phase seems to be very different from that in July 1972, period seems to be somewhere between 700 and 1000 kHz.

Again, no systematic effects with bandwidth, number of channels, declination or time were found. In addition, there was no effect (to well within the probable errors) as a function of rotation angle.

Conclusions: In 1971 and 1972, the baseline of the 21-cm Mark III autocorrelator used in conjunction with feeds 3 and 4 of the four feed system on the 300-foot NRAO telescope showed maximum deviations from a straight line of not more than 0.20K over a 5 MHz bandwidth. The deviations were in the form of a sine-wave pattern with a period of 800 kHz and amplitudes depending on the feed used and the observing period varying from 0.20K to less than 0.08K. No large-scale deviations (of the order of a few MHz) from a straight line were detected (<.05K). Over observing periods of two to three weeks, the shape of the baseline stayed perfectly constant. It did not vary with rotation angle of the feed or with declination, nor with the configuration of the Autocorrelation receiver. From one observing period to the next, however, large changes in amplitude and phase (but not period) occurred. The basic shape and amplitude was similar to that measured in 1969 and 1970, before the resurfacing of the telescope.

It seems to follow from this that telescope parameters have little effect on the baseline. Feed rotation (the feeds are off-axis by about 1.5 beamwidths) and considerable changes in the telescope surface did not have any influence, nor did the addition of an elaborate structure near the focal plane (the low-frequency moving feed). Also, the IF-filter section and autocorrelation section of the receiver seemed to have no influence, as different bandwidths and autocorrelator configurations gave identical results. Thus, we suspect that the deviation of the baseline from a straight line may be due to effects in the parametric amplifiers and their cable connection to the feeds.

The extremely stable baseline made it possible to remove its effect from the 21-cm line profiles, even though for the Maryland-Green Bank Galactic 21-cm Line Survey, where the r.m.s. noise is slightly less than 1K, such corrections were not really necessary.

This report was distributed to interested parties in 1970
and is attached for your information

The frequency-dependent baseline of the 400-channel receiver at 21-cm with the 300-foot 4-feed system.

by G. Westerhout and H. U. Wendlandt
University of Maryland

June 1970

1. Initial measurements.

1. October 1969.

During the month of October 1969 the 400 channel receiver, with the 4-feed system was used on the 300-foot telescope. During the first four days, feed 4 was connected to receivers A and C, and feeds 1 and 3 could be connected, with the flip of a switch, to receiver B. During the rest of the month, after paramp 4 died, feed 2 was connected to receivers A and C. Since receiver A is the one used in the series mode, most baseline information is available for feed 2, both from receiver A in series (wide band) and from receiver C.

A program was written by one of us (H.U.W.) for the 360-50 in Charlottesville, which created one average line profile for each scan suitable for baseline determination. A straight-line baseline was then fitted by least squares to those portions of the profile (the two end sections) where no hydrogen emission was expected. In the profiles chosen the velocity limits between which hydrogen emission was expected were -65 and +65 km/sec, with only few exceptions. This straight-line baseline was then subtracted and the resulting profiles plotted with the Calcomp plotter on a scale where a T_A of 1°K= 2 inches and 1 MHz=9.5 inch for receivers A and B; for receiver C, 1°K= 1 inch and 1 MHz= 2.8 inch. For receivers A and B the average of every four points was plotted, while for receiver C a running average of two points was plotted. Hence, the A plot has either 96 (series) or 48 (parallel) points, B has 48 points, and C has 29 points. A vertical line was drawn at the position of zero-frequency (since an instrumental quantity is being determined, local-standard-of-rest corrections are not applicable). The plots were arranged in groups; for periods of up to 24 hours of observing time, profiles with the same receiver characteristics were plotted together. Scans suitable for baseline determination are those scans where the 21-cm line emission is narrow in width. This is true in general at higher latitudes, where special scans were made once a day, and near the galactic anti-center. All scans taken with appropriate receiver settings and satisfying these conditions were used.

The plots with 1.25 MHz bandwidth did not turn out to be very useful, since wings of line profiles down to a level of 1°K in general fill up 3/4 of this band. For the 2.5 MHz wide profiles, well over half is baseline and thus a good impression can be obtained of the baseline shape and its changes with time. Finally, some 5 MHz wide profiles with receiver C provided an even better overall look.

Feed 4 was used from 2 - 6 October 1969. Over 5 MHz bandwidth it showed deviations from a straight-line of less than ± 0.15°K, and these were in the form of a sine wave pattern, barely distinguishable from noise, with an amplitude of about 0.1°K and a period of about 2 MHz.

From October 6 through 31, Feed 2 was the main feed, and all wide-band measurements of the baseline were made with this feed. The general shape was a curvature as a function of frequency which would fit a "sine wave" with an amplitude of about 0.1°K and a period of about 6-8 MHz. However, super-imposed on this was another quasi-sine-wave pattern with amplitude 0.15 to 0.20°K and period about 1 to 1.5 MHz. The latter was also clearly visible in the 2.5 MHz scans with receiver A in the series mode. It is this shorter-period sine wave which will mostly influence baselines of profiles with 2.5 and 1.25 MHz bandwidth, as they have their baseline determined by fitting a straight line to the extreme 20 to 500 kHz on each end. The amplitude of this short-period sine wave varied somewhat as a function of time. In particular, on October 25-26 the amplitude was at least two times smaller than normal.

Baseline scans with Feeds 1 and 3 unfortunately were only made with 1.25 MHz bandwidth, so that almost no region free of hydrogen emission is available. Those profiles where some comparison with the Feed 2-baseline is possible show no indication that the baseline shape is any worse than that of Feed 2. We shall therefore assume that the conclusions for Feed 2 hold for 1 and 3 also. This assumption is strengthened by the observations in May 1970 (see below).

The general features of the baseline of Feed 2 for October 1969 are illustrated in Figure 1.

2. May 1970

From April 28 to May 5 a survey program was run which was identical in its set-up to that of October 6 - 30, i.e., Feed 2 was used for receivers A and C, Feeds 1 and 3 for receiver B. This time, very many scans were available with 2.5 MHz bandwidth at high latitudes, so that a very accurate determination could be made of the baseline of Feed 2. Also, a reasonable number of scans was available for Feeds 1 and 3. Because no 5 MHz wide scans were made, the 6-8 MHz period "sine" wave found in October could not be confirmed. The baseline for Feeds 2 and 3 had a sine wave pattern with amplitude .15°K ±.05 and period 800 kHz ± 100. Feed 1 had about the same period, but an amplitude of about 0.1°K. The phase of the sine wave is different for the three Feeds. Throughout the eight days, the shape of the baseline remained constant to within ± 0.1°K. Figure 2 shows the baseline for this period.

3. Conclusions.

It is clear that if a straight-line baseline is fitted to the end points of a 1.25 or 2.5 MHz profile, the deviations of the real baseline from this straight-line will not exceed 0.3°K and will usually be smaller. The r.m.s. noise for an effective bandwidth of 7 kHz and an effective integration time of 30 sec is approximately 1°K. The effects of the error beam of the 300-foot telescope cannot possibly be removed to better than 5°K at the higher intensities, and the contour intervals on the Maryland-Green Bank Survey maps are 5°K. Least-squares determination of a straight-line baseline leads to an r.m.s. error in the baseline of an individual record between 0.1 and 0.5°K. In view of all these other uncertainties, the effects of deviations of the baseline from a straight-line are entirely negligible.

Since the various Feeds behave differently, and the baseline changes as a function of time, it appears as though much of the deviation of the baseline from a straight-line is due to the electronics and/or the connections between Paramps and Feeds. It would be extremely useful if the cause of the baseline curvatures could be explained in terms of certain electronics and cabling adjustments, so that for highly sensitive measurements the baseline could be trimmed to achieve a much better approximation to a straight-line.

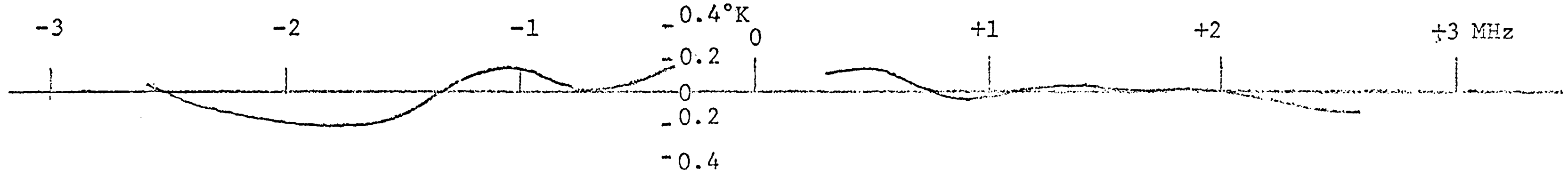

Figure 1 Average shape of the baseline of Feed 2 in October 1969.

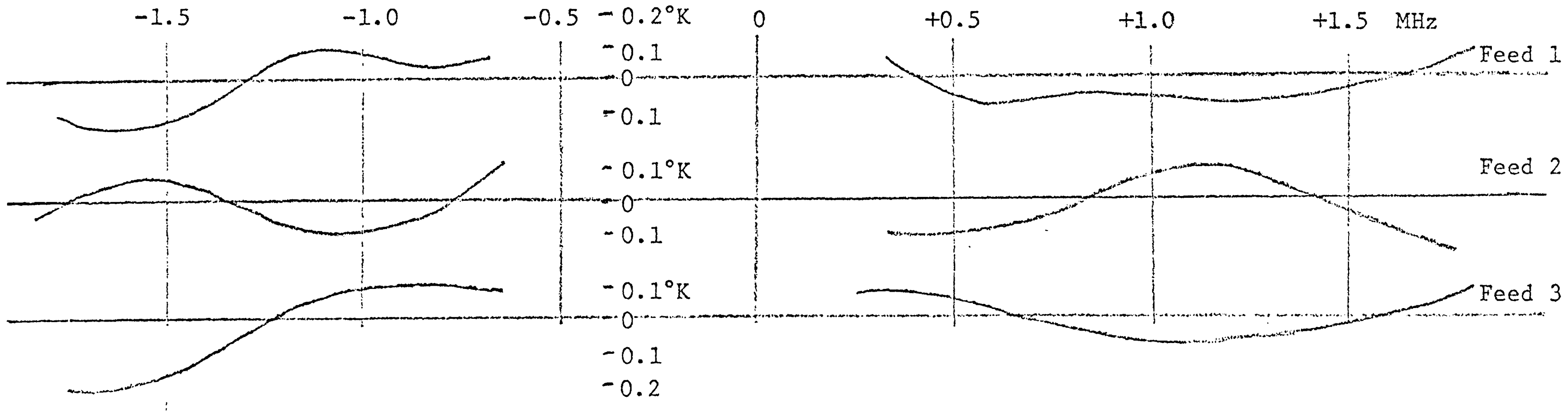

Figure 2 Average shape of the baseline of Feeds 1, 2 and 3 in May 1970. The zero-point of the frequency scale is 1420.40 MHz.