Instrumental Delays at the GMRT

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07/Jan/2002

Abstract

On systematic study of the instruemental delay at the GMRT we find: (1) The instrumental delay at GMRT can be sufficiently accurately measured such that systematic variations of ~ 0.1 m[1] on timescales of 10-20 minutes can be reliably detected. (2) For a fixed observing setup the typical variation of the instrumental delay is ~ 0.4 m on timescales of 20 days (3) The difference in instruemntal delay between the two polarizations is by and large < 5 m, although on a couple of antennas it is > 10 m[2], (4) The instrumental delay typically changes by ~ 1 m on switching from a 32 MHz IF bandwidth to a 16 MHz IF bandwidth and (6) The change in instruemental delay on switching between different front ends is typicaly ~ 5 m, although on a few antennnas it is > 15 m.

1 Introduction

Fig. 1 is a block diagram of the principal delays encountered in the signal path from any given GMRT antenna. There is a geometric delay τ_g(which arises due to the path length differences between the source to the different antennas), then a delay in the SAW filter at the first IF (τ_{s_1}), then a delay in the SAW filter at the second IF (τ_{s_2}) and a transmission delay in the optical fiber at the same second IF (τ_{Fb}). In the CEB the signal is assumed to undergo no further delays until digitization. After digitization various delays and corrections are applied. Corrections for $\tau_g$have been discussed in, among others Chengalur (1998). Here we discuss corrections for the the combination $\tau_i = \tau_{s_1} + \tau_{Fb} + \tau_{s_2}$, which called the "instrumental delay". At the GMRT the instruemntal delay (also called the "fixed delay"[3]) is traditionally given in units of meters, i.e. one works in terms of the quantity $c\, d\tau$, where c is the speed of light. From hence forth we will work in these units, but continue to refer to the quantity measured as a "delay."

An error $d\tau$ in the instruemntal delay for a given antenna will give rise to a phase gradient (across channels) in the bandpass of that antenna[4] To be precise, the error in the instrumental delay is related to the phase gradient across the band by the relation

[1]For people who find it easier to think in terms of phase gradients we note that a delay error of 1 m corresponds to a phase gradient of 19.2 degrees across a 16 MHz bandwidth.

[2]Please note that this does not include any possible systematic offset between the two polarizations, see section 2.

[3]We do not use the term "fixed delay" in this report, because of the confusion it might engender in the mind of the reader were one to attempt to constrain the time variability of a quantity so named.

[4]A delay error also leads to decorrelation. Throughout this report however we deal only with delay errors that are so small that the decorrelation they produce is negligible.

GMRT Delay Block Diagram

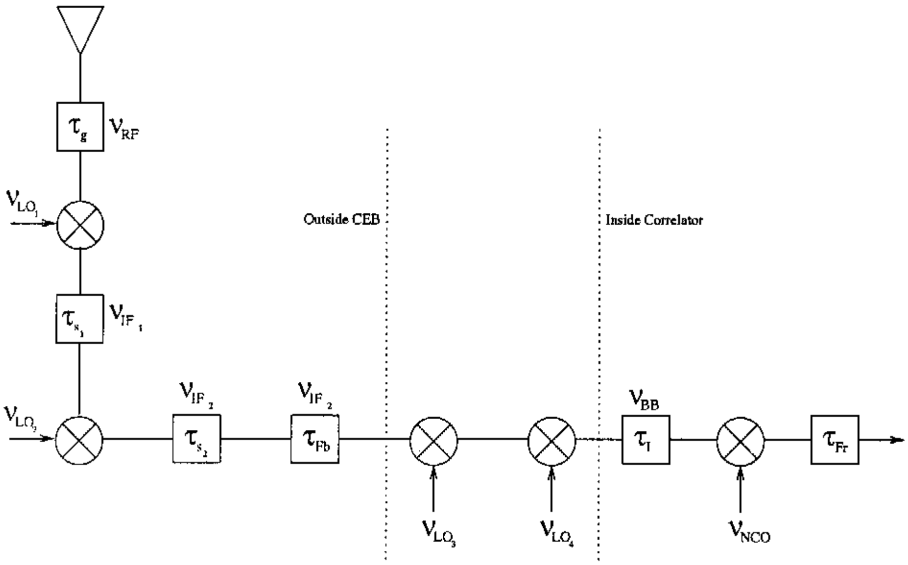

Figure 1: Block Diagram illustrating the various delays suffered by the astronomical signal at the GMRT.

$$d\tau = \frac{1}{2\pi}\frac{d\Phi}{d\nu} \quad (1)$$

where $d\tau$ is in seconds, $d\nu$ is in Hz and $d\Phi$ is in radians.
The instrumental delay can hence be measured by the following recipe.

1. Observe a strong calibrator. Decompose the visibilities into antenna based complex gains. This can be done using the program rantsol (Bhatnagar 1999,2001).

2. Fit a straight line to the phase across the band, and use equation 1 to determine the corresponding delay error. This can be done using the program fdelay (written by J. Chengalur, documentation can be found online and in Chengalur & Bhatnagar 2001).

Note that since one is fitting to the measured bandpass, the bandpass shapes of all the amplifiers and filters in the signal path are also folded in into the measured delay. Since we are only interested in relative delays, it is only the unit to unit differences in the SAW filters and other electronic elements along the signal path and the differences between the fiber delay and the reference delay that matter. This report addresses various issues regarding the instruemntal delay, viz. (i) On what timescale does the instrumental delay vary? (ii) Is the instrumental delay the same for the two polarizations? and (ii) Does the instrumental delay change (and if so by how much?) as one changes parameters like the observing frequency, the IF bandwidth, etc. The final adopted delays are tabulated in the Appendix.

2 Difference betwen 130 and 175 Pols

The signals from the two polarizations are transmitted to the Central Electronics Building (CEB) on the same optical fiber (the two polarization signals are frequency multipled onto the same fiber). Since all the electronic components are supposed to be close to "identical" for the two polarizations, the instrumental delays for the two polarizations are expected to be similar. Indeed in the Mark IV 16 MHz correlator delay correction cannot be done independently for the two different polarizations.

Fig. 2 shows a histogram of the measured delay differences between the two polarizations (This is the differences at 32 MHz IF bandwidth, 1280 MHz RF and averaged over a 5 hr period, i.e. the same data as is used in Sect. 3.1). As can be seen for most antennas the instrumental delay is the same to within ~ 5 m for the two polarizations. For C11 and E02 however the differences are greater than 10 m. All antennas except C02 were available at the time of this measurement. The rms of the difference (for all antennas excluding C11, E02, C02) is 3.2 m.

Note that since we only measured the co-polarized visibilities, we are not sensitive to any possible systematic delay difference between the two polarizations. For example, if the 130 MHz polarized signals were all delayed by a fixed amount τ_{pol} from the 175 MHz polarized signals, our observations would be unable to detect it. The only way to measure such signals would be via measurements of cross-polarized visibilities. Such a measurement was done by Gupta & Kudale (2001) and they find evidence for a systematic offset.

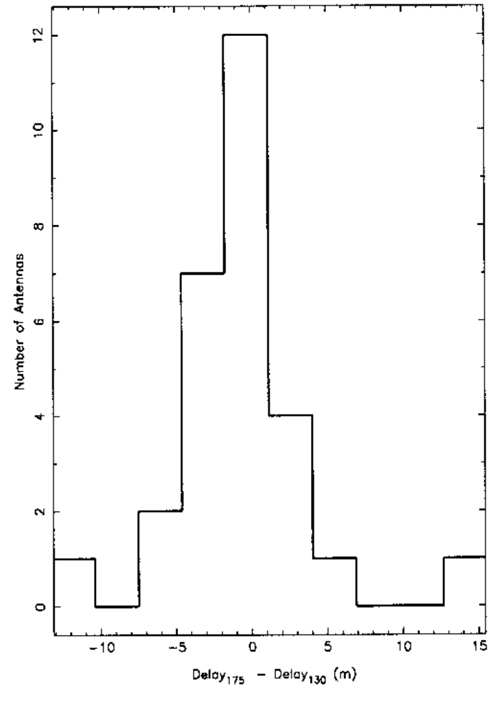

Figure 2: Histogram of the differences between the instrumental delay for the 130 MHz and 175 MHz polarizations. For most antennas the difference is < 5 m. For two antennas (C11 and E02) the difference is greater than 10 m.

3 Time Variability

3.1 Short Term Variability

The short term variability was measured using a $\sim$ 5 hour scan on 3C147 taken on 10 Nov 2001. The RF frequency was 1280 MHz, and the IF and BB bandwidths were 32 and 16 MHz respectively. All antennas except C02 were available. The delays were measured (from the recorded data) at intervals of $\sim$ 5.6 minutes by running rantsol and fdelay in a shell script.

The short term behaviour of the instrumental delays falls into two classes. (1) "Good" antennas. For these antennas the instrumental delay varies by about ± 0.1 m on timescales of 10-20 minutes. This variation is highly correlated between the two polarizations. A selection of these antennas is shown in Fig. 3[Left]. (2) "Bad" antennas". For these antennas the instrumental delay varies by upto ± 1 m on timescales of 10-20 minutes. This variation is not necessarily correlated between the two polarizations. A selection of these antennas is shown in Fig. 3[Right]. On this observing run, the antennas which showed such behaviour were C04,C06,C09,C11,S04,S06 and E03. Note that we find not trend in short term variability with fiber length, i.e. the arm antennas are not particularly worse (or better) than the central square antennas.

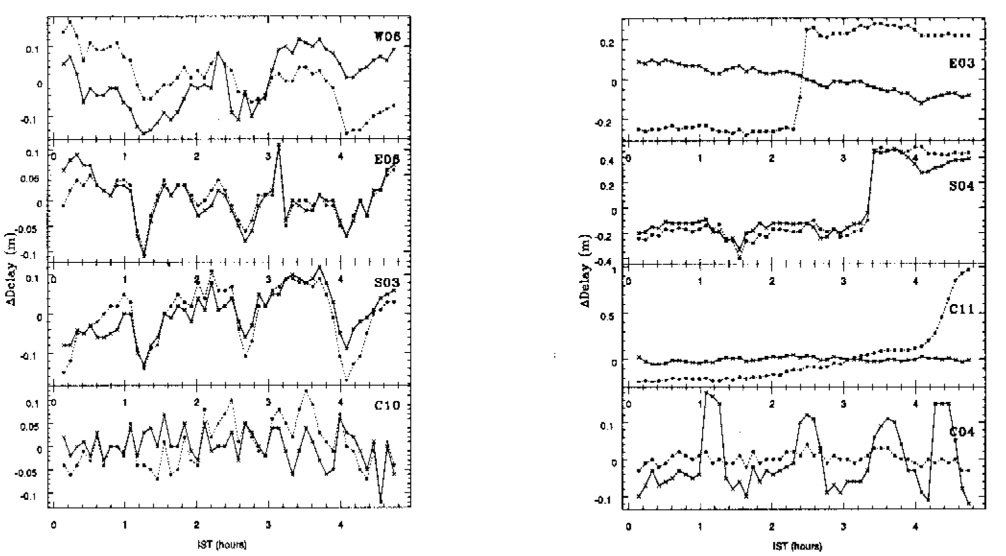

Figure 3: **[Left]** Short term variability of the instruemntal delay on "Good" antennas. The solid line is the 130 polarization and the dashed line is the 175 polarization. The average delay (per polarization) has been removed before plotting. "Good" antennas show no abrupt delay jumps and the delay changes are highly correlated between the two polarizations. **Right]** Short term variability of the instruemntal delay on "Bad"antennas. The solid line is the 130 polarization and the dashed line is the 175 polarization. The average delay (per polarization) has been removed before plotting. "Bad" antennas show large abrupt delay jumps which are not necessarily correlated between the two polarizations.

To ilustrate what a delay difference of $\sim$ 0.6 m looks like in practise we show in Fig. 4 the bandpass of S04 for two records, one before and one after the delay jump seen in Fig. 3[Right]. As can be seen the phase is actually dominated by an oscillatory pattern. The oscillations are presumably produced by electronic elements along the signal path. Many antennas (including the "good" ones) show such oscillatory patterns, which are generally stable with time. In the case of S04 however, the pattern appears to have changed abruptly, and the difference between the old and the new pattern contains a linear term (see the solid line in Fig. 4). It is this linear term that has been interpreted as a delay jump.

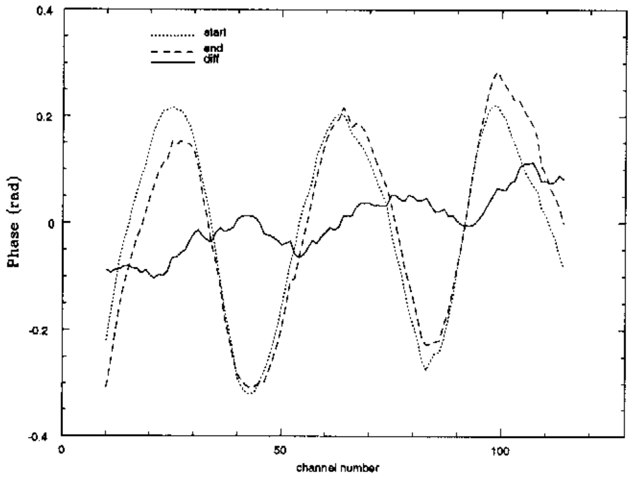

Figure 4: Phase across the band for S04 before and after the delay jump seen in Fig. 3[Right]. The bandpass phase is dominated by oscillations produced by various electronic elements along the signal path. The difference between the "before" and "after" spectra (solid line) shows a linear trend, which as explained in the text is treated as a "delay change". There is no measureable change in the ampltiude or the overall phase associated with this "delay" jump.

A histogram of the delay differences over this ~ 5 hr observing period is shown in Fig. 5 separately for the "Good" and "Bad" antennas. The rms delay variation for the "Good" antennas is ~ 0.06 m, while the rms delay variation for the "Bad" antennas is ~ 0.15 m.

3.2 Long Term Variability

The instruemental delays were again measured on 18 Nov 2001 (using observations of 3C48) and on 02 Dec 2001 (using observations of 3C147). The set up was identical to that used for the observations of 3C147 on 10 Nov 2001 (see Sect. 3.1). The histograms

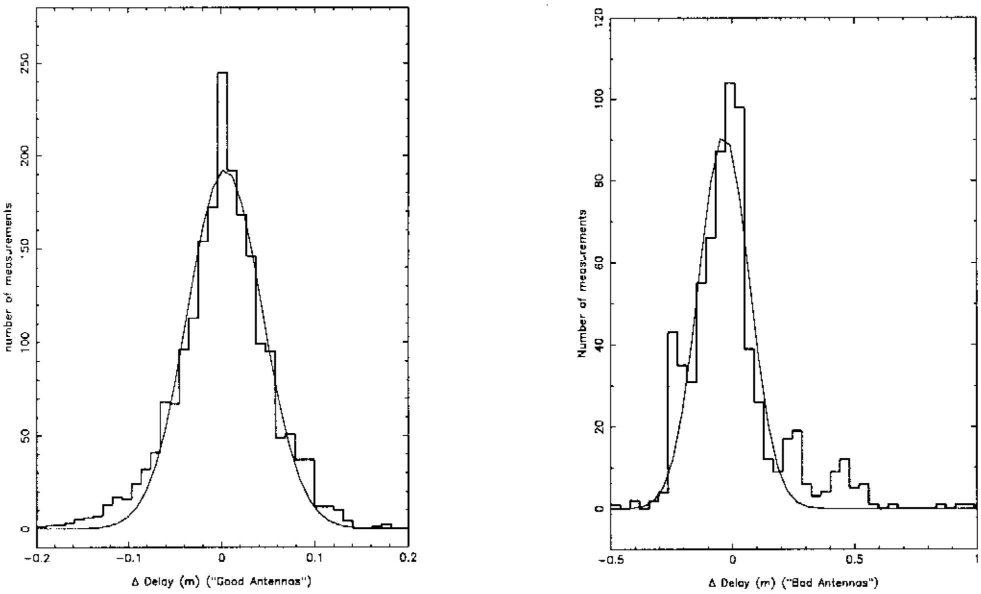

Figure 5: [**Left**] Histogram of the variability (over $\sim$ 5 hr) of the instrumental delay for "Good" antennas. The rms of the variability is $\sim$ 0.06 m. [**Right**] Histogram of the variability (over $\sim$ 5 hr) of the instrumental delay for "Bad" antennas. The rms of the variability is $\sim$ 0.15 m. See the text for a discussion of how antennas are classified as "Good" or "Bad".

of the instruemental delay differences[5] are shown in Fig 6. The rms of the differences in the instrumental delay measured 8 days apart is 0.27 m and 22 days apart is 0.38 m.

4 Variation with Observing Parameters

As discussed above the short and long term stability of the instrumental delay is fairly good. On these grounds alone it is not neccessary to calibrate the instrumental delays separately for each observation. On the other hand it is still not clear whether the delays change with observational parameters, viz. the IF, RF and BB settings. Since the number of possible combinations at the GMRT is effectively a countable inifinity, we restrict ourselves to two cases which we feel are particularly important, viz. (i) a change in the IF bandwidth. The IF bandwidth is set using SAW filters which have substantial delay associated with them. Changing from one set of filters to another could hence lead to changes in the instrumental delays. (ii) Changes in the observing frequency.

4.1 IF Bandwidth

Changing the IF parameters at the GMRT can take up to a few minutes but asdiscussed in Sect. 3.1 the instrumental delay changes only very slightly on such timescales.

[5]The 175 MHz polarization of C11 has been excluded from its comparision since its value on 10 Nov is systematically different (by $\sim$ 2.5 m) from that on 18 Nov and 02 Dec. C11 175 pol also showed has poor short term stability on 10 Nov.

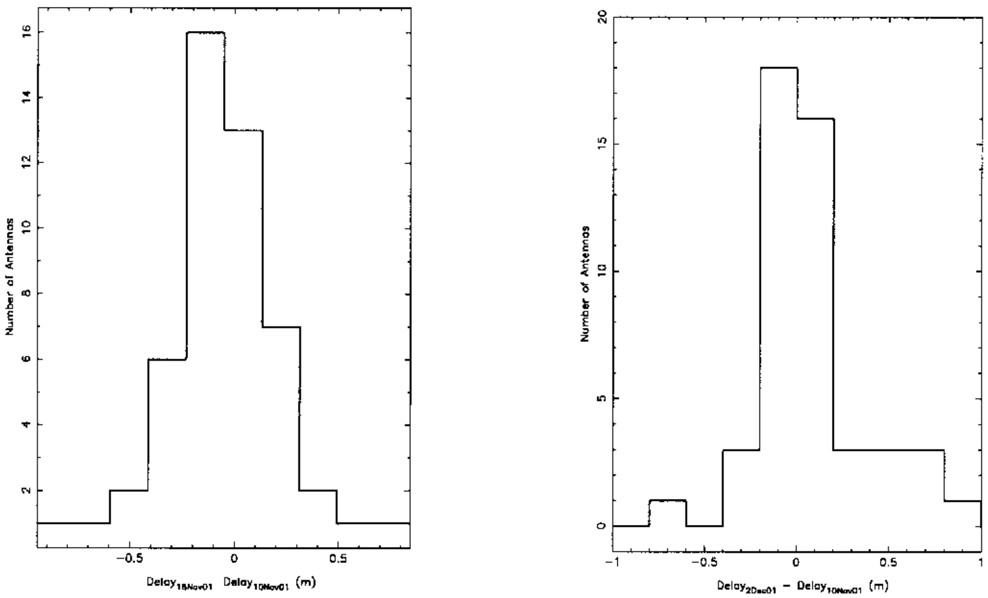

Figure 6: **Left** Histogram of the differences between the instrumental delay measured 8 days apart. The observing setup was the same on both days. The rms of the change in instrumental delay is 0.27 m. **Right** Same as the left panel but for a separation of 22 days between the measurements. The rms of the change in instrumental delay is 0.38 m.

The instrumental delay was measured for IF bandwidths of 16 MHz and 32 MHz and a fixed BB bandwidth of 8 MHz. This was done for observing frequencies of 1390 and 1280 MHz. A histogram of the instrumental delay differences for these two bandwidths is shown in Fig. 7[Left]. As can be seen the difference can be significant, upto ± 4 m. The rms in the variation of the instrumental delay is 0.96 m.

4.2 Observing Frequency

The instrumental delay was measured for observing frequencies of 1280 and 1390 MHz and a fixed BB bandwidth of 8 MHz. This was done for IF bandwidths of 16 and 32 MHz. A histogram of the instrumental delay differences for these two observing frequencies is shown in Fig. 8[Left]. As can be seen the difference can be significant, upto ± 6 m. There also appears to be a systematic difference between the two observing frequncies, viz. most antennas appear to have a smaller instrumental delay at 1280 MHz than at 1390 MHz. The rms in the variation of the instrumental delay is 1.96 m.

Figure 9 shows a histogram of the instrumental delay differences as measured using the 610 MHz observations (on 14/Dec/01) and 1280 MHz observations (on 02/Dec/01). Ideally one should not have had such a large time difference between the two measurements. However, recall from Sect. 3.2 that delay drifts (for identical observational setups) are typically ~ 0.4 m over time periods of ~ 20 days. The difference between these two measurements is however ~ 3.80 m, i.e. the expected slow drift is negligible compared to the systematic differences between the instrumental delays at 610 MHz and 1280 MHz.

Acknowledgements: Useful Discussions with Y. Gupta regarding the delay differences between the two polarizations are gratefully acknowledged.

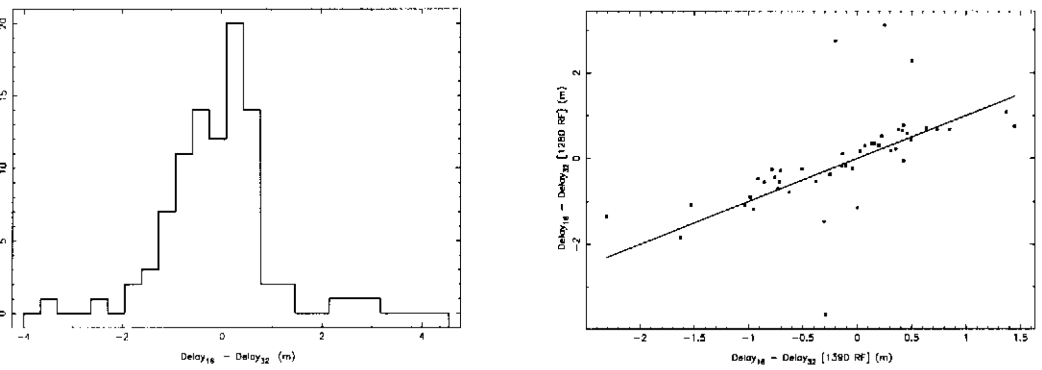

Figure 7: **[Left]** Histogram of the differences between the instrumental delay measured for a 16 MHz and 32 MHz IF bandwidth. The BB bandwidth was 8 MHz for both observations. The rms of the delay variation is 0.96m. **[Right]** Plot of the delay difference between 16 MHz and 32 MHz IF bandwidths at 1390 MHz observing frequency vs. the delay difference between the same two IF bandwidths at an observing frequency of 1280 MHz. The solid line has slope=1 and intercept=0. The change in instrumental delay as one changes the IF bandwidth is esentially independent of the observing frequency, as one would expect.

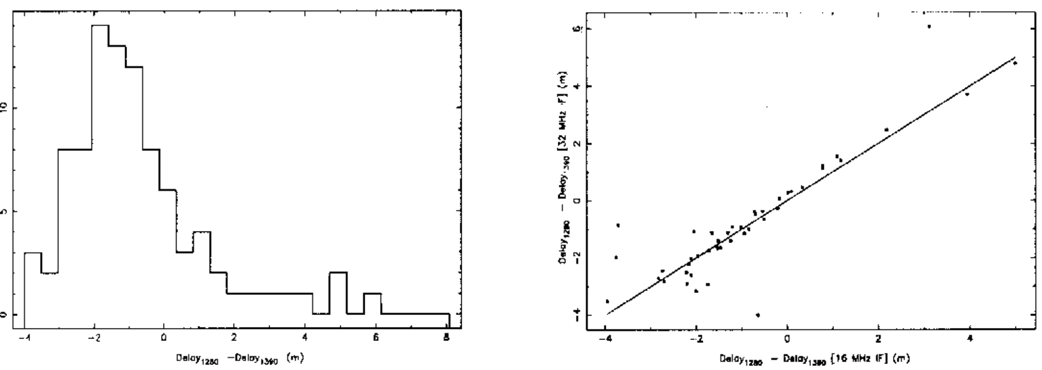

Figure 8: **[Left]** Histogram of the differences between the instrumental delay measured for observing frequencies of 1280 MHz and 1390 MHz. The BB bandwidth was 8 MHz for both observations. The rms of the delay variation is 1.96m. **[Right]** Plot of the delay difference between observing frequencies of 1280 and 1390 MHz at an IF bandwidth of 16 MHz vs. the delay difference between the same two observing frequencies at an IF bandwidth of 32 MHz. The solid line has slope=1 and intercept=0. The change in instrumental delay as one changes the observing frequency is esentially independent of the IF bandwidth, as one would expect.

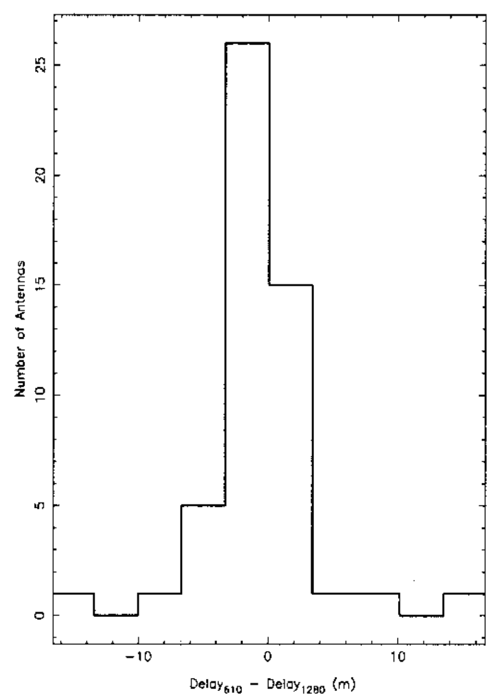

Figure 9: Histogram of the differences between the instrumental delay measured for observing frequencies of 610 MHz and 1280 MHz. The rms of the delay difference is 3.80m.

5 Appendix: Adopted Delay Values

Antenna	Delay (m)	Antenna (m)	Delay (m)	Antenna	Delay (m)
C00	-497.89	C11	-285.32	S02	-9231.79
C01	176.92	C12	-1049.69	S03	-13835.30
C02	585.09	C13	-1363.75	S04	-18673.49
C03	476.54	C14	-427.01	S06	-27966.45
C04	77.25	E02	-3956.66	W01	-1339.92
C05	86.13	E03	-7920.26	W02	-4646.78
C06	-201.02	E04	-13983.29	W03	-9636.54
C08	-466.54	E05	-20609.70	W04	-15283.65
C09	256.61	E06	-25311.11	W05	-21590.15
C10	-445.68	S01	-5502.96	W06	-29266.87

Table 1: Adopted delays for different Antennas

6 References

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