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Comparison of the Output of Repeated Mark III and Mark IV Correlation Results

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Abstract

During the transition phase from the Mark IIIA to the Mark IV correlator but also at later stages of the maturing Mark IV correlator a number of correlations of the same session was carried out at the MPIFR/BKG Correlator Center in Bonn. Comparisons of the results provide a good insight into the repeatability of the correlation process. It is found that at the latest stage the repeatability of Mark IV correlations in terms of WRMS differences between two correlations is on average on the order of 6 picoseconds (ps) for the X band delay observables and 50 ps for S band. On the other hand, the larger scatter of differences between the results from the "old" and the "new" correlator persists.

1. Introduction

The transition from the Mark IIIA to the Mark IV correlator at the MPIFR/BKG Correlator Center (Max Planck Institute for Radio Astronomy/Bundesamt für Kartographie und Geodäsie) in Bonn early in the year 2000 has significantly improved the efficiency and the capacity of routine correlation processes (Alef et al. 2000; Alef and Müskens 2001). During the time of the change-over the tapes of an IRIS-S session (IS148, 2000.03.27) with four stations (Wettzell, Westford, Fortaleza and HartRAO) had been ear-marked for multiple correlations with the Mark IIIA and the Mark IV correlator. The purpose of re-correlations was and still is to carry out a quality assessment of the correlators in various stages of their development and maturing. By investigating the repeatability of the correlation results, the accuracy of the correlation process can be characterized.

Following a previous publication of a first comparison of correlation results with the two correlators (Müskens et al. 2000) we now present a refined analysis of the correlation results concentrating on the group delay observables. In the meantime four different correlations with different correlator and fringe fitting software for the determination of the delay observables have been carried out (Table 1).

Correlation Label	Correlator and software version	Fringe fitting program and version
A	Mark IIIA	FRNGE
B	Mark IV (2000.06.15)	fourfit V0 (2000.08.02)
C	Mark IV (2000.12.15)	fourfit V3 (2001.08.01)
D	Mark IV (2001.04.19)	fourfit V3 (2001.08.01)

Table 1. Correlation and fringe fitting dates and versions

In the following comparisons all observations with signal-to-noise ratios (SNR) of less than 10 are excluded in order to free the intercompared data from erroneous fringe fitting results due to marginal detection levels and their more arbitrary consequences.

2. Mark IIIA (A) versus Mark IV (B)

The first comparison is carried out between the correlation with the Mark IIIA correlator and a correlation with the Mark IV correlator in an early stage of development. Due to different algorithms for the acceptance of accumulation periods, the fringe fitting programs (FRNGE and fourfit) were found to end up with different reference epochs for the individual observations of the Mark IIIA and the Mark IV correlations. Epoch differences could be as large as 3 seconds. It was therefore necessary to apply a suitable interpolation routine in order to determine the delay differences at the median epoch. Here, we used a linear interpolation applying the corresponding delay rates for the transformations to the median epoch before forming the differences. This method worked quite reliably since the scatter in the delay differences did not increase with increasing epoch differences.

Table 2. Group delay differences (Mark IV (B) minus Mark III (A))

Baseline			X band		S band	
			delay bias	WRMS	delay bias	WRMS
			ps	ps	ps	ps
Fortaleza	–	HartRAO	2.5	20.9	38.3	112.2
Fortaleza	–	Westford	-2.3	22.7	-1.7	91.2
Fortaleza	–	Wettzell	3.3	24.7	-3.4	121.2
HartRAO	–	Westford	-7.4	31.5	-16.8	116.4
HartRAO	–	Wettzell	-1.1	23.4	12.2	78.7
Westford	–	Wettzell	-0.2	16.7	18.7	96.1

Forming the weighted RMS differences of identical scans and excluding observations with SNRs < 10 yielded biases for each baseline for X-band on the order of a few picoseconds (ps) and an average WRMS difference of 23 ps (Tab. 2). At S-band the biases were one order of magnitude larger and the WRMS differences are 103 ps.

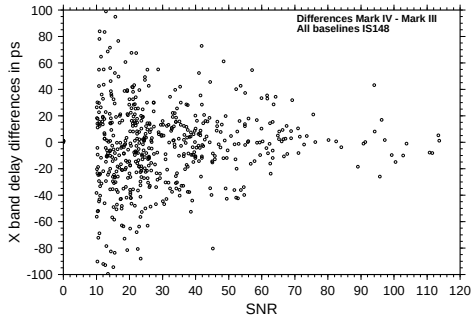

Figure 1. X band delay differences versus SNR

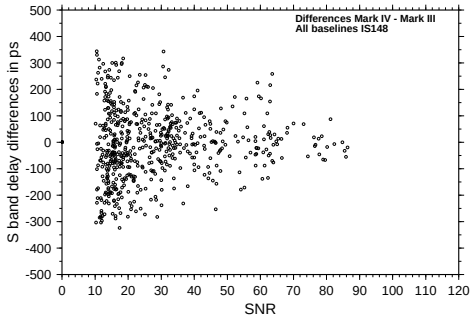

Figure 2. S band delay differences versus SNR

More interesting than the sheer numbers are graphical representations of the differences. While delay differences versus time only show a random scatter, delay differences versus SNR are more informative. Figures 1 and 2 show the X-band and S-band differences versus SNR for all baselines

of the network together.

It is immediately obvious that the scatter is largest at low SNRs with a progressive reduction at higher SNRs. This effect appears in both, X- and S- band, with maximum differences of 100 ps at X-band and of up to 350 ps at S-band. If the same plots are produced for individual baselines, they show identical characteristics though with less data. No baseline dependent effects are seen.

3. Mark IV (C) versus Mark IV (D)

The second comparison is carried out for two Mark IV correlations at a very stable stage of the correlator development. The only difference in terms of the procedures used for the Mark IV versus Mark IV comparisons is the fact that here all reference epochs are identical and interpolation is not required. The weighted RMS scatter in the differences amounts on average to 6 ps at X-band and 50 ps at S-band.

Table 3. Group delay differences (Mark IV (D) minus Mark IV (C))

Baseline	X band		S band	
	delay bias ps	WRMS ps	delay bias ps	WRMS ps
Fortaleza – HartRAO	0.26	7.1	-8.3	53.7
Fortaleza – Westford	-0.30	5.3	1.7	48.5
Fortaleza – Wettzell	0.49	7.7	-9.0	60.3
HartRAO – Westford	0.93	6.1	4.5	37.0
HartRAO – Wettzell	0.65	6.9	9.4	59.6
Westford – Wettzell	0.39	4.9	-3.0	41.8

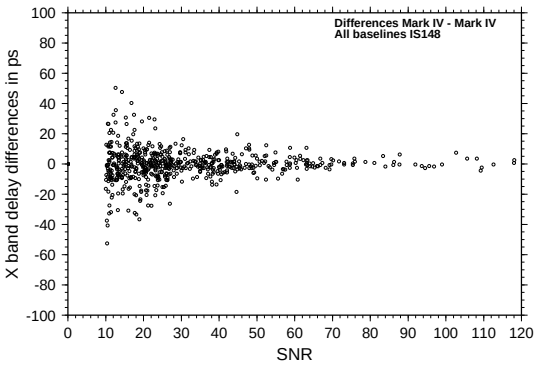

Figure 3. X band delay differences versus SNR for all baselines.

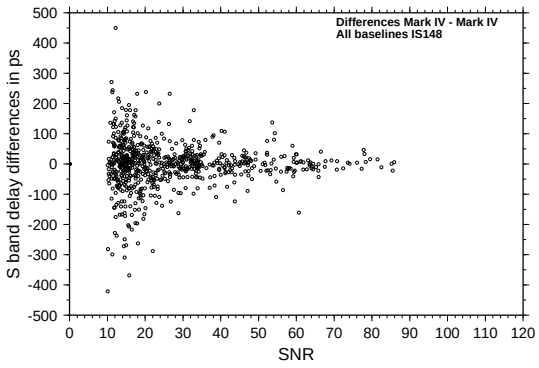

Figure 4. S band delay differences versus SNR for all baselines

We see that the scatter in the differences is much smaller than in the case of the Mark IIIA – Mark IV comparison. Looking at the graphical representation of the differences we see a similar pattern as in the previous case. From a correlator/fringe fitting point of view it should be expected that the reliability of the delay determination increases with higher SNR. In addition, the lower the SNR the higher the formal error and, thus, the smaller the impact on the geodetic parameter estimation process. To test this, the delay differences were normalized with their formal errors. Figures 5 and 6 show the corresponding distributions for X- and S-band which show only slightly hyperbolic envelopes. This is a good indication that there are no remaining systematic effects beyond the random variations in the delay observables which depend only on the SNR.

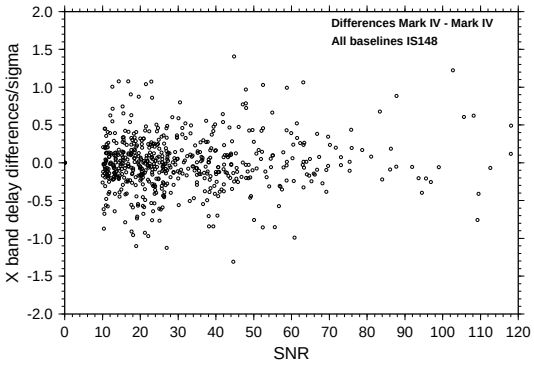

Figure 5. Normalized X band delay differences versus SNR

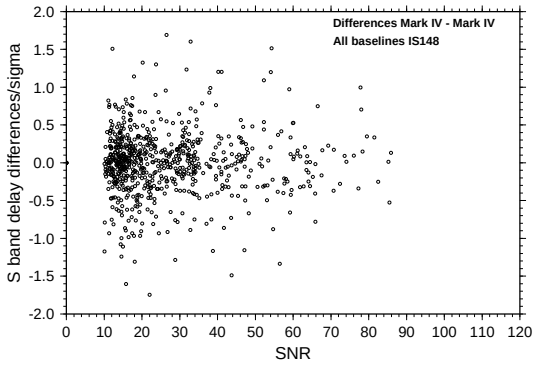

Figure 6. Normalized S band delay differences versus SNR

4. Mark III (A) versus Mark IV (D)

In April 2001 when the last one of this series of Mark IV correlations (D) was carried out, the Mark IV correlator had reached a certain level of maturity as compared to the time of the first Mark III – Mark IV comparison. It is, therefore, quite interesting to see whether the improvements in the correlator software in the years 2000 and 2001 have brought the Mark IV results closer to the original Mark IIIA correlator output. Table 4 lists the results of the comparisons.

Table 4. Group delay differences (Mark IV (D) minus Mark III (A))

Baseline	X band		S band	
	delay bias ps	WRMS ps	delay bias ps	WRMS ps
Fortaleza – HartRAO	1.5	20.3	9.1	130.9
Fortaleza – Westford	-0.6	21.9	-3.5	105.5
Fortaleza – Wettzell	0.8	22.9	-26.3	101.0
HartRAO – Westford	-4.5	27.7	-17.4	113.3
HartRAO – Wettzell	-2.5	20.2	20.8	93.5
Westford – Wettzell	-0.6	13.4	0.6	95.1

These numbers do not differ very much from the comparison of the Mark IIIA correlation with the early Mark IV correlation as listed in table 2, although for S-band the WRMS scatter is even a bit larger here. The same holds true for the graphical representations as depicted in figures 7 and 8.

5. Conclusion

In conclusion it can be stated that none of the comparisons showed any systematic differences between any two correlations carried out in this project. The biases found are not significant considering the corresponding WRMS noise and, hence, do not degrade the quality of the correlations.

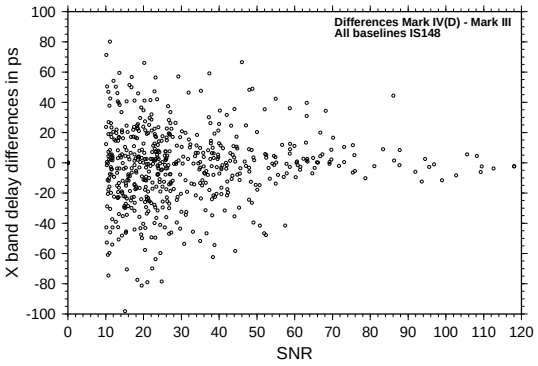

Figure 7. X band delay differences versus SNR for all baselines.

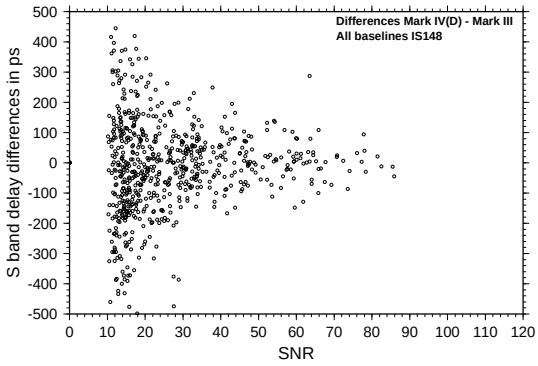

Figure 8. S band delay differences versus SNR for all baselines

If we assume that the hard- and software of the Mark III and the Mark IV correlators are of equal quality the correlations with the two correlators may be seen as repeated processes and the differences can be considered as representing an external repeatability of two different correlators. The comparison of the original Mark IIIA correlation with two Mark IV correlations at different development stages has shown that all of the software improvements between June 2000 and April 2001 have not reduced the level of the noise in the differences. The WRMS scatter of the differences of about 21 ps at X-band and about 100 ps at S-band persists even after all initial flaws of the Mark IV correlator software have been eliminated.

With the comparison of two Mark IV correlations which were carried out at a relatively stable period of correlator hard- and software, we are able to quantify an internal repeatability induced by one and the same correlator. The WRMS scatter is only 6 ps at X-band and 50 ps at S-band with the typical reciprocal dependency on the SNR level.

Low SNR observations are always affected by higher uncertainties, but although the reduced weights of the observations in the geodetic parameter estimation process take care of this deficit, the measured delays may still be off by several tens of picoseconds or more. Therefore, we strongly suggest that in the design of observing schedules more emphasis is placed on higher SNR rather than to have as many observations as possible with short duration and low SNR.

References

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