Feasibility of using phase delays in geodetic VLBI data analysis

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Abstract

The summary of the report about investigation of feasibility of using phase delay in geodetic VLBI data analysis carried out in the Geodetic Institute of the University of Bonn in 1997–2000 is presented.

1 Introduction

Feasibility of using phase delay observables in geodetic VLBI has been investigated. Uncertainty of phase delays measurements determined by a thermal noise is better than the uncertainty of measurement of group delay by the factor $\frac{F_r}{F_e}$ where F_r is a phase reference frequency, F_e is an effective bandwidth. This ratio is about 40 for a narrow (360MHz) frequency setup and about 20 for a wide (700MHz) frequency setup. Using phase delays instead of group delay would promise dramatic increasing precision provided thermal noise is the dominant source of errors. However, phase delay can be determined only up to an arbitrary number of phase turns. The smallness of phase delay ambiguity spacings: 120 psec (only 3 cm!) at X-band is a challenge.

I was trying to build an algorithm for resolving phase delay ambiguities and to answer the questions:

- What are the conditions when we are still able to resolve phase delay ambiguities?
- What are the advantages using phase delay observables?
- Is it feasible to use phase delay observables in routine processing VLBI data?
- What kind of changes in observation strategy should be done for using phase delay observables?

2 What did I find

I developed several algorithms for resolving phase delay ambiguities and implemented them in the software package SOLVE. I resolved ambiguities at about 150 sessions. I find that

1. Problems of resolving phase delay ambiguities at short baselines and long baselines are quite different. We are able to ignore contribution of troposphere and ionosphere at the baselines shorter than 5–10 km. The latter factor is essential since we can use single-band observables. Ambiguities at short baselines can be resolved always unless severe instrumental problems were detected. I have resolved phase delay ambiguities at all short-baseline experiments (68 experiments) except 1.

2. Technique for resolving phase delay ambiguities at long baselines (longer than 10 km) is quite different. The threshold is the length where the random fluctuations of ionosphere delay may reach 1/6 of a phase ambiguity spacing: 20 psec. This threshold is about 10 km. From the other side increasing baseline length beyond this threshold doesn't spawn additional difficulties: to resolve phase delay ambiguities at the baseline with length 10 km is as difficult as to resolve ambiguities at the baseline with length 9000 km. There are some difficulties with dealing very long baselines: longer than 80

3. Algorithm for resolving phase delay ambiguities in a multi-baseline session should preserve phase delay closure for each scan. Using this condition allowed to achieve substantial improvement in our ability to resolve ambiguities. The more stations participated in the scan, the better since closure criteria became more powerful what reduces the probability of error in resolving phase delay ambiguities.

4. To resolve phase delay ambiguities at S-band is more difficult than to resolve ambiguities at X-band: ambiguity spacings at S-band are larger by 4 times but contribution of ionosphere is larger by 12 times.

5. Ionosphere free linear combination of X-band phase delay and S-band group delay, so-called PX_GS combination is the preferable combination of the observables which use phase delay.

6. Using pure combinations of X-band and S-band phase delays gives only a marginal improvement of precision with respect to using PX_GS combinations but it is much more difficult to guarantee that the ambiguities has been resolved correctly when this combination is used.

7. It is feasible to resolve phase delay ambiguities for 80% of observations in the best VLBI experiments and then to use PX_GS combination.

8. I didn't find the way to resolve phase delay ambiguities before getting first the excellent group delay solution. There are too few chances to resolve phase delay ambiguities if wrms of group delay solution exceeds 25 psec for some baselines. Sessions which gives wrms of group post-fit residuals of group delay solution below 20 psec are eligible for phase delay ambiguity resolution.

Obstacles before resolving phase delay ambiguities:

- Thermal noise. In general sensitivity at S-band is still not enough. Formal uncertainty of determination of group delay at S-band below 100 psec is required. This problem will be overcome when full capacity of MARK-IV system will be used.

- Instrumental errors. It was found that instrumental errors are a significant source of errors which was underestimated early. If some cases it becomes a dominating source of noise. Procedure of computation of formal uncertainties by the post-processing software has some deficiencies and formal error of *measurements* of group and phase delays is systematically underestimated (in addition to errors in a model of, f.e. atmosphere origin). Reducing instrumental errors is still a challenge.

The main problem is not to resolve ambiguities, but to guarantee that phase delay ambiguities have been resolved correctly. There are qualitative criteria when we can say that resolving ambiguities is unsatisfactory or it has been done perfectly, but the problem of developing a criterion for establishing the exact boundary has not been yet solved.

I found that there is a source of errors, probably of instrumental origin, which affect phase delay observables. It was found that this source of errors is a phase-dependent: scattering post-fit residuals of X-band phase delay solution is 4 times larger than scattering S-band phase delay solution. This source of noise puts the floor of uncertainties of phase delay observables: 5 psec for X-band observables, and 20 psec for S-band observables.

Using PX_GS combination after resolving phase delay ambiguities gives fit with wrms of post-fit residuals 8–10 psec what is 2–3 times better than a combination of group delays was in use. But I didn't find an evidence that a baseline length repeatability of phase delay delay solutions is better. One of the possible explanation is that the dominating source of errors affecting repeatability for the data set which I used was not a thermal noise of group delay observables.

3 Main results of the research:

- Program GAMB for group delay ambiguity resolution was developed;
- Algorithms for phase delay ambiguity resolution was developed and program PAMB which implements them has been created;
- Software for outliers elimination with ability to improve original resolution of phase delays on the fly has been developed.
- Phase delay ambiguities at both long and short baselines for about 150 sessions has been resolved. Phase delay solutions were investigated and compared with group delay solutions.
- Influence of spurious signals on phase calibration was investigated. Numerical model of contribution of this source of instrumental errors was build. Program Phase_Doctor which allows to investigate station performance and to compute contribution due to this effect to phase and group delay has been developed. It was shown that influence of noise in phase calibration after applying this correction is reduced below 2 psec level.
- Another source of instrumental errors: instrumental polarization was investigated. Two special VLBI experiments has been carried out and processed.
- Conclusions about feasibility of using phase delay observables in VLBI data analysis has been drawn:

4 Conclusions

1. Phase delay ambiguities at short baselines can be resolved always.
2. Phase delay ambiguities at long baselines can be resolved for the best VLBI sessions, but we still unable to guarantee that this resolution is unique.
3. MARK-III system doesn't have enough sensitivity to resolve phase delay ambiguities at long baselines routinely;
4. Instrumental errors are the main obstacle before resolving phase delay ambiguities. The problem of instrumental errors in VLBI has been underestimated.
5. Nowadays is it is not feasible to use phase delay observables in routine processing VLBI observations but situation may change in near future.

5 Publications

1. L. Petrov "Usage of phase delay measurements produced by VLBI for geodetic applications", Annales Geophysicae, Supp. 1 to Vol. 16, 1998, p. C399.

2. L. Petrov "Towards Phase Delay VLBI", 1998 AGU Fall meeting, Suppl. to Eos, Transactions, AGU Volume 79, 1998, p. F197.

3. L. Petrov "Steps towards phase delay VLBI", In Proceedings of the 13th Working Meeting on European VLBI for Geodesy and Astrometry, ed. by W. Schlueter and H. Hase, BKG, Wettzell, p. 144-151, 1999.

4. L. Petrov "Instrumental errors of geodetic VLBI" (submitted to the Proceedings of the 1-st IVS General meeting, ed. by N. Vandenberg, 2000)