Differential calibration of BIPM P3 systems: Long term study

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This memorandum expands the long term study of differential calibration of the BIPM dual frequency GPS receivers (hereafter P3 systems), initially provided in section 2 of the Memorandum TM172. Results of a differential calibration are the electrical delays of the calibrated system (receiver + antenna) for each frequency P1/P2 with respect to the delays of the reference system. The reader is directed to TM172 and references therein for details on the quantities involved in calibration exercises.

Several P3 systems have been installed at the BIPM, listed below those with significant duration and those still present:

- BP0C (Ashtech Z12T) between 2000 and 2013
- BP0M (Ashtech Z12T) between 2004 and 2014
- BP0R (Septentrio PolaRx2) since 2006
- BP0T (Dicom GTR50) since 2007
- BP0U (Dicom GTR50) since 2008 (new antenna in 2010)
- BP1C (Septentrio PolaRx3) since 2009 (new firmware in September 2014)
- BP1B (TTS-4) since 2010 (considered since 2015)
- BP1J (Septentrio PolaRx4) since 2012
- BP1K (TTS-4) since 2014 (considered since 2015)
- BP1X (GTR51) since 2014

Since 2004, when at least two systems were available at the BIPM, these systems have been periodically differentially calibrated, i.e. all measurements have been carried out in the same manner as in a true calibration exercise. Twenty-one such exercises have been carried out over 11 years (see Table 1 for a list). This memorandum presents results of these differential calibration exercises to study the long term stability that can be expected from such systems.

The conventional reference of the BIPM calibrations

In the first years, the natural reference system was BP0C (Z12T) which has been at the BIPM since 2000 and has been absolutely calibrated in 2001. However this unit also served as the absolute reference for UTC calibrations (see TM116) thus was a traveling system for many years. Therefore it was deemed more secure and practical to use the second Z12T BP0M as the conventional reference for analyzing these differential calibrations results.

In end 2013 both BIPM Z12T units started to show signs of aging and in the course of year 2014 both units were stopped. The role of conventional reference was then transferred to BP0R, a Septentrio PolaRx2 present since 2007. All results that had been computed with reference to BP0M were reformulated with reference to BP0R.

Type	Ashtech Z12T		PolaRx2	PolaRx3	PolaRx4	Dicom GTR50		GTR51	Piktime TTS-4	
Receiver ID	BP0M	BP0C	BP0R	BP1C	BP1J	BP0T	BP0U	BP1X	BP1B	BP1K
May 2004	☺	☺								
February 2005	☺	☺								
March 2005	☺	☺								
January 2006	☺	☺								
May 2006	☺	☺								
November 2006	☺	☺	(1)							
February 2007	☺	☺								
June 2007	☺	☺								
August 2007	☺	☺								
December 2007	☺	☺	☺			☺	☺			
March 2008	☺	☺	☺			☺	☺			
December 2008	☺	☺	☺			☺	☺			
June 2009	☺	☺	☺			☺	☺			
November 2009	☺	☺	☺	☺		☺	☺			
December 2009	☺	☺	☺	☺		☺	☺			
July 2010	☺	☺	☺	☺		☺	☺(2)			
October 2011	☺	☺	☺	☺		☺(3)	☺			
May 2012	☺	☺	☺	☺	☺	☺	☺			
April 2013	☺	☺	☺	☺	☺	☺	☺			
February 2014 (4)	☺		☺		☺	☺		☺		
December 2015			☺	☺(5)	☺	☺	☺	☺	☺	☺

Table 1: List of differential calibration exercises for the BIPM P3 systems.

(1) A 2006 measurement of BP0R was off by about 5 ns and is not reported here.
(2) Starting 2010, BP0U has a new antenna and is considered as a new system.
(3) Starting 08/2010, BP0T has a new antenna cable and is here considered as a new system.
(4) The laboratory was transferred to a new location and all receivers were moved between October 2013 and February 2014. This change should not affect the continuity of the differential calibration results.
(5) Starting 09/2014, BP1C has a new firmware and is considered as a new system.

Long-term comparison of differential calibrations

Figures 1 to 6 present the results of differential calibrations as differential values of INTDLY (Reference – Study) where reference is BP0M for Figure 1 and 2, and BP0R for figures 3 to 6. Results are presented for P1, P2, P1-P2, and P3. Arbitrary values have been removed to fit all four results on the same scale, therefore only the stability is meaningful. We note that Figure 2 (BP0M-BP0R) relates the two systems used as conventional reference over the period.

As a general result, the long term stability of the INTDLY values is of order 1 ns RMS for P1 and P2, and somewhat less for (P1-P2).
We note that all comparisons over up to 4 years (Figures 3-6) have maximum RMS values of 0.8 ns for P1 or P2 and 0.6 ns for (P1-P2). Longer comparisons (Figures 1-2) have RMS values that reach or exceed 1 ns for P1 or P2 (they don't exceed 1 ns if one removes the last "end of life" value of the Z12Ts), but remain below 1 ns for (P1-P2). Inferred P3 values are more variable due to the combination of P1 and P2, and can exceed 2 ns RMS. Excluding the end-of-life Z12Tpoint, peak to peak variations are below 4 ns for P1 or P2 in the worst case (over 9 years, see Figure 1), of order 3 ns for (P1-P2) and below 8 ns for P3.

Conventional values of internal delays of BIPM receivers

Because the long term stability of the systems seems satisfactory, we derive conventional values for the internal delays (receiver+antenna) for all considered BIPM systems, consistent with the original absolute calibration of BP0C (P1=305.6 ns; P2=321.9 ns, see TM116). Table 2 below updates the corresponding table in TM172 and the values have been rounded to the nearest half ns. Note that such conventional values are « long-term averages » derived from measurements taken over the entire period of operation of the receivers, as indicated in Table 1. They may differ from values determined to be in agreement with the Group 1 ensemble of receivers in the BIPM calibration scheme [TM243].

System	**P1**	**P2**
BP0C Z12-T	**305.6 ns**	**321.9 ns**
BP0M Z12-T	**304.5 ns**	**323.0 ns**
BP0R PolaRx2	**222.5 ns**	**224.5 ns**
BP1C PolaRx3 (until 2014)	**55.0 ns**	**58.0 ns**
BP0T GTR50 (1) after 08/2010 (2)	**-5.0 ns**	**-3.5 ns**
BP0U GTR50 (1) after 05/2010 (3)	**-7.0 ns**	**-2.0 ns**
BP1J PolaRx4	**54.5 ns**	**53.5 ns**

Table 2: Conventional values of hardware delays of the BIPM reference systems.
(1) Values for GTR50 are corrections to the values entered in the receiver software
(2) Change of antenna cable for BP0T in Aug. 2010
(3) Change of antenna for BP0U in May 2010

Discussion

In terms of long term stability, the available results do not clearly allow identifying one system that could be considered less stable than others. Assuming no common systematic effect, we might conclude that the level of long-term (4-year) instability for a link between two such systems may be at a level of order 1 ns RMS for both P1 and P2, and below 2.5 ns for P3. This is consistent with the values, taken from [Jiang et al. 2011], chosen to express the aging of calibration uncertainty in the new BIPM calibration scheme.

Recently the set of reference receivers of nine Group 1 laboratories has been calibrated and the P1/P2 reference values have been set so as to minimize changes for the NMIJ, OP and PTB systems with respect to their values from past BIPM calibrations using BP0C, see TM243. A "Group 1 compatible" calibration result has then been derived for BP0R INTDLY as 222.6 ns for P1 and 224.8 ns for P2. This result can thus be considered as derived from the original BP0C calibration through the stability of three GPS systems in three different laboratories (NMIJ, OP, PTB). On the other hand, the BP0R values in Table 2 are derived from BP0C from seven years of comparisons involving three GPS systems at the BIPM. Their close coincidence indicates that GPS calibrations can remain stable at the 1 ns level over very long periods through a set of three systems.

Acknowledgements

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References

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- Petit G., "Values and uncertainties of the hardware delays of BIPM geodetic systems and estimation of the type B uncertainty of P3/PPP link calibrations", BIPM TM.172, December 2009.
- Petit G., "Determination of reference GPS "INTDLY" values of Group 1 geodetic receivers in the initial Group 1 trip (Cal_Id = 1001-2014)", BIPM TM.243, V6 July 2015.
- Jiang Z., Arias F., Lewandowski W., Petit G., BIPM Calibration Scheme for UTC Time Links, Proc. EFTF 2011, pp 1064-1069, 2011.

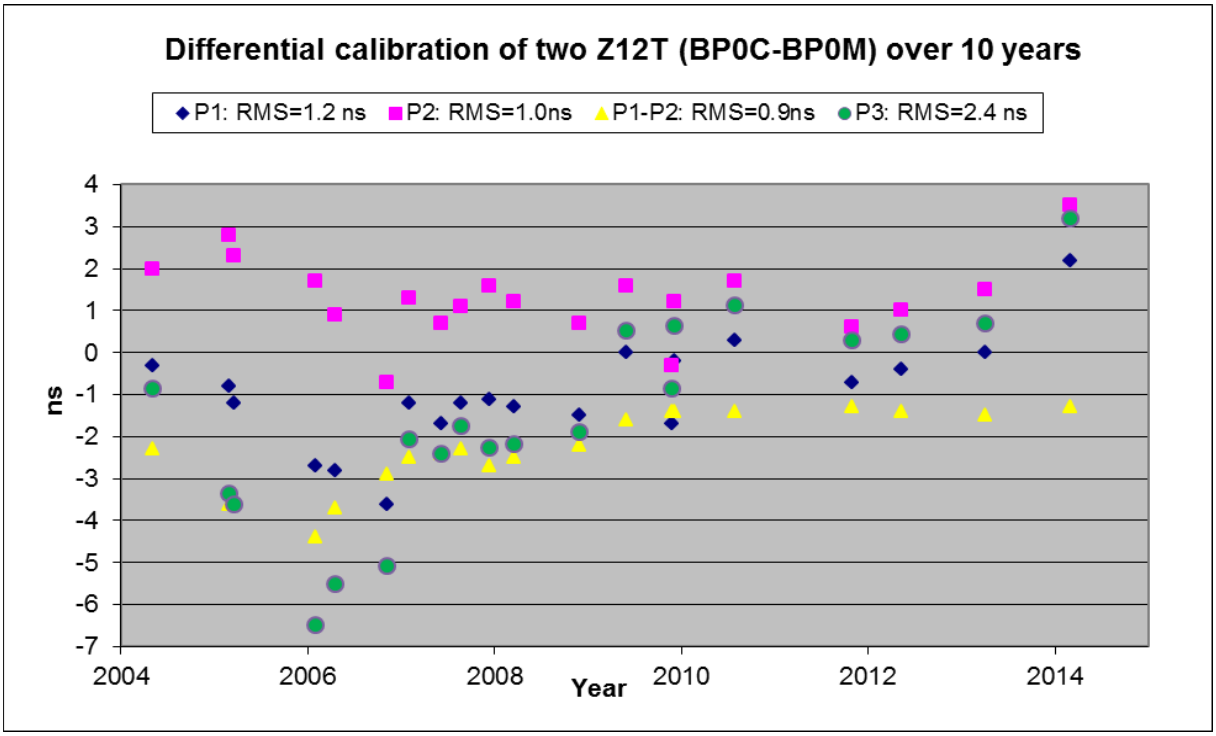

Figure 1: Differential calibration of the Z12T BP0M vs. BP0C (results arbitrarily offset)

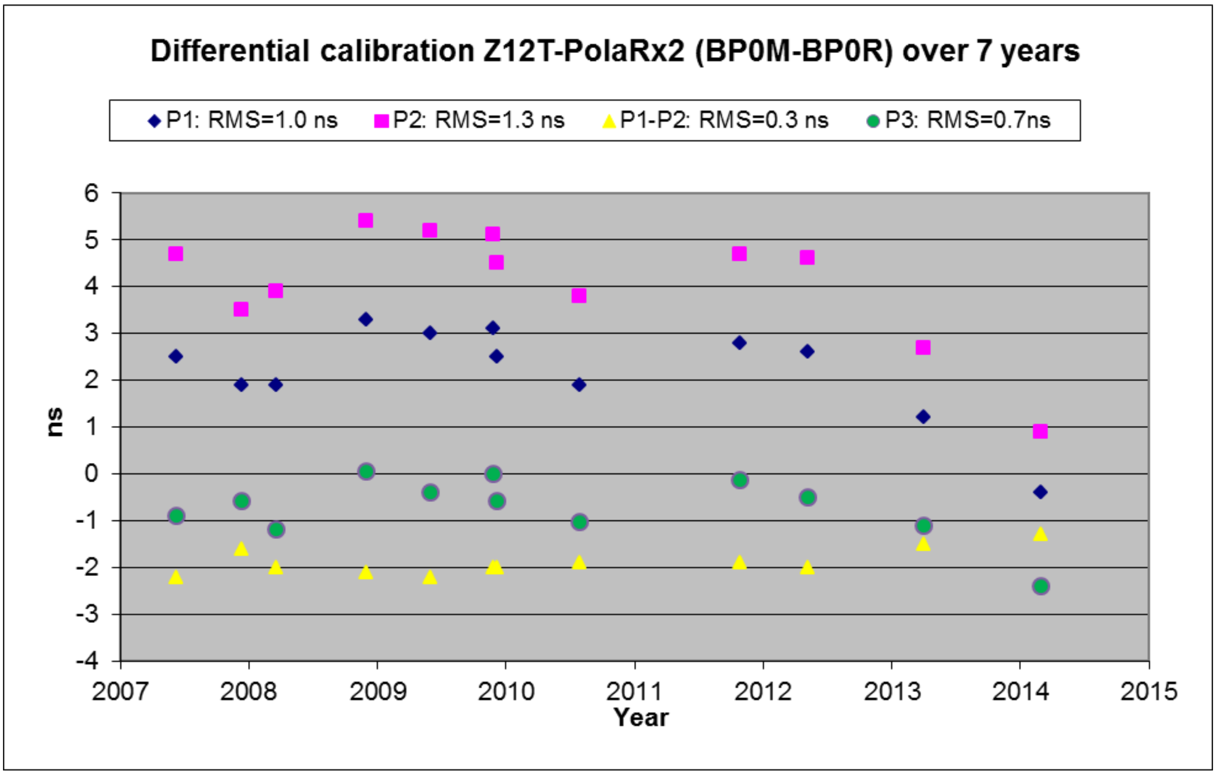

Figure 2: Differential calibration of the PolaRx2 BP0R vs. BP0M (results arbitrarily offset)

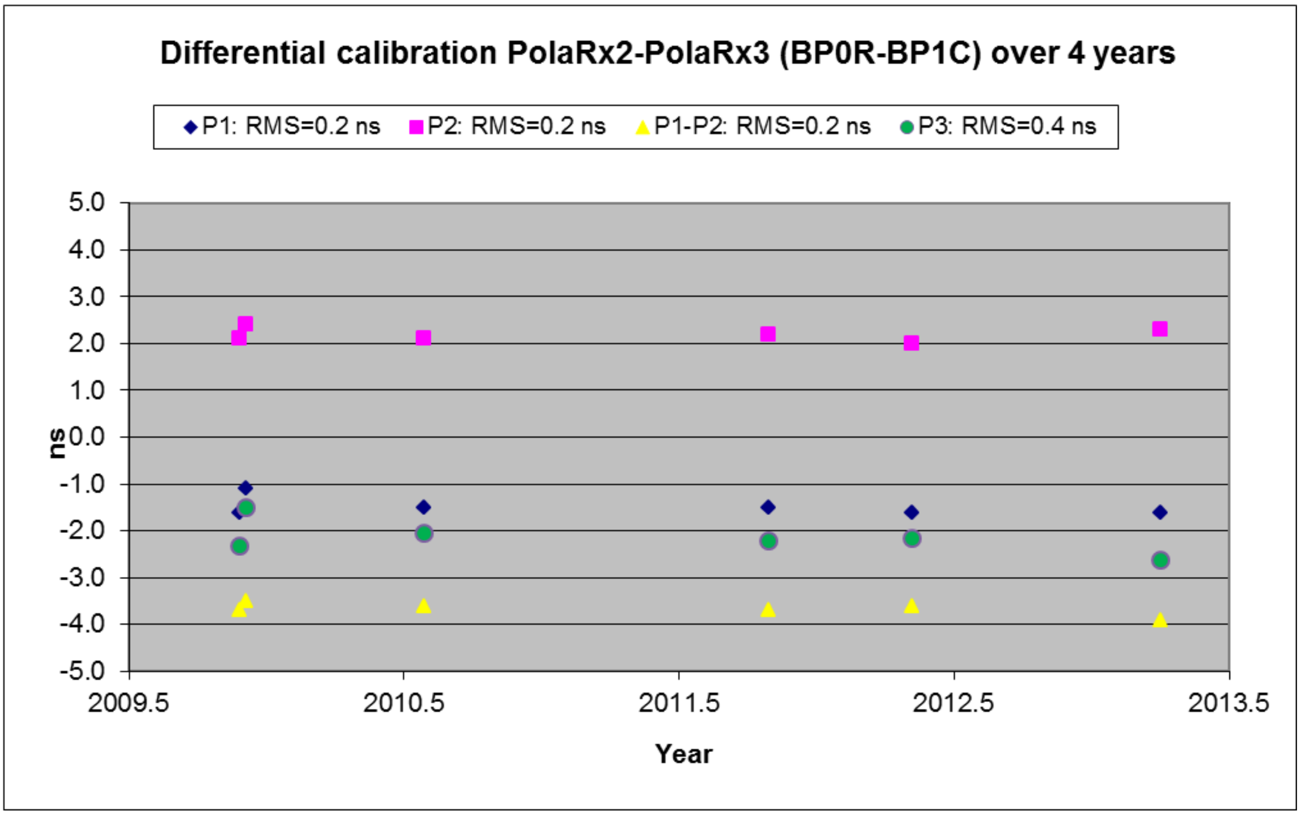

Figure 3: Differential calibration of the PolaRx3 BP1C vs. BP0R (results arbitrarily offset). BP1C is still operational but has new firmware.

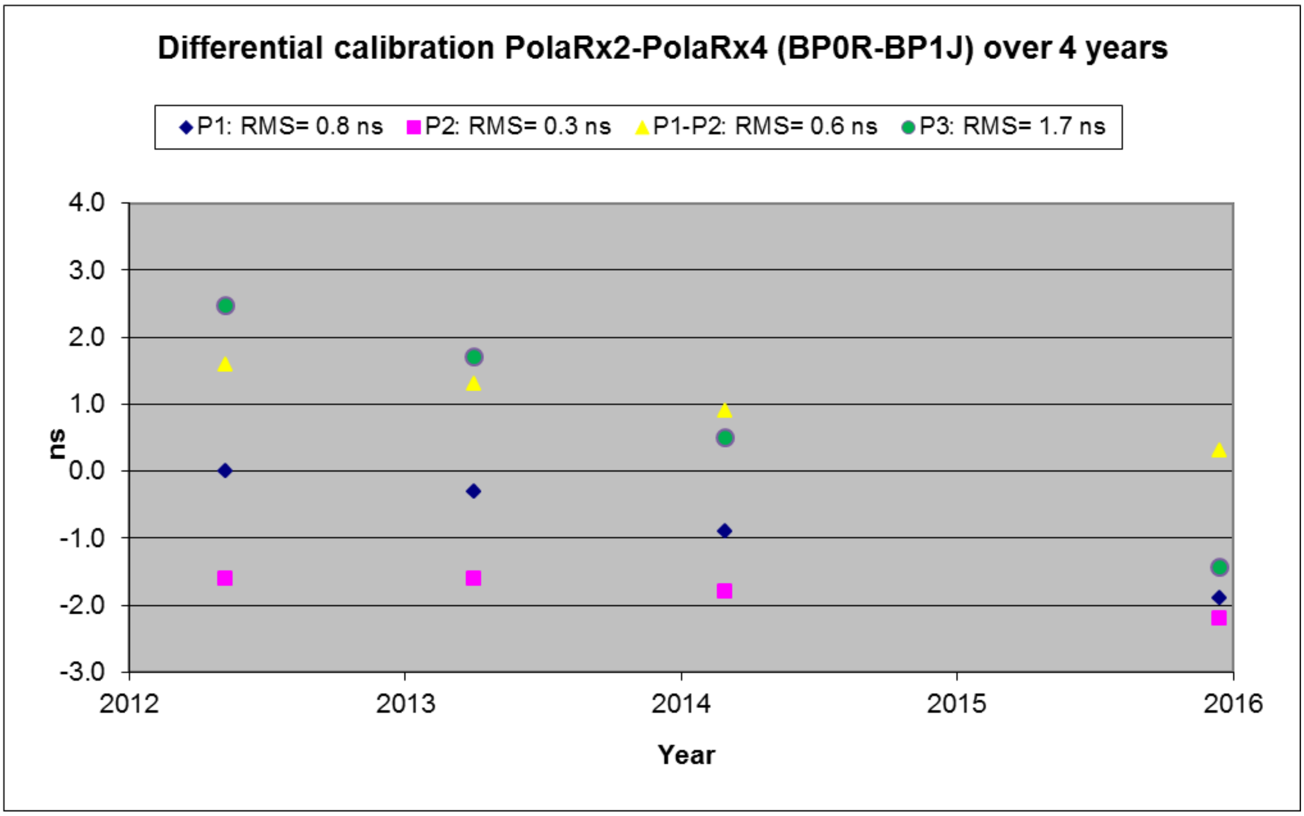

Figure 4: Differential calibration of the PolaRx4 BP1J vs. BP0R (results arbitrarily offset).

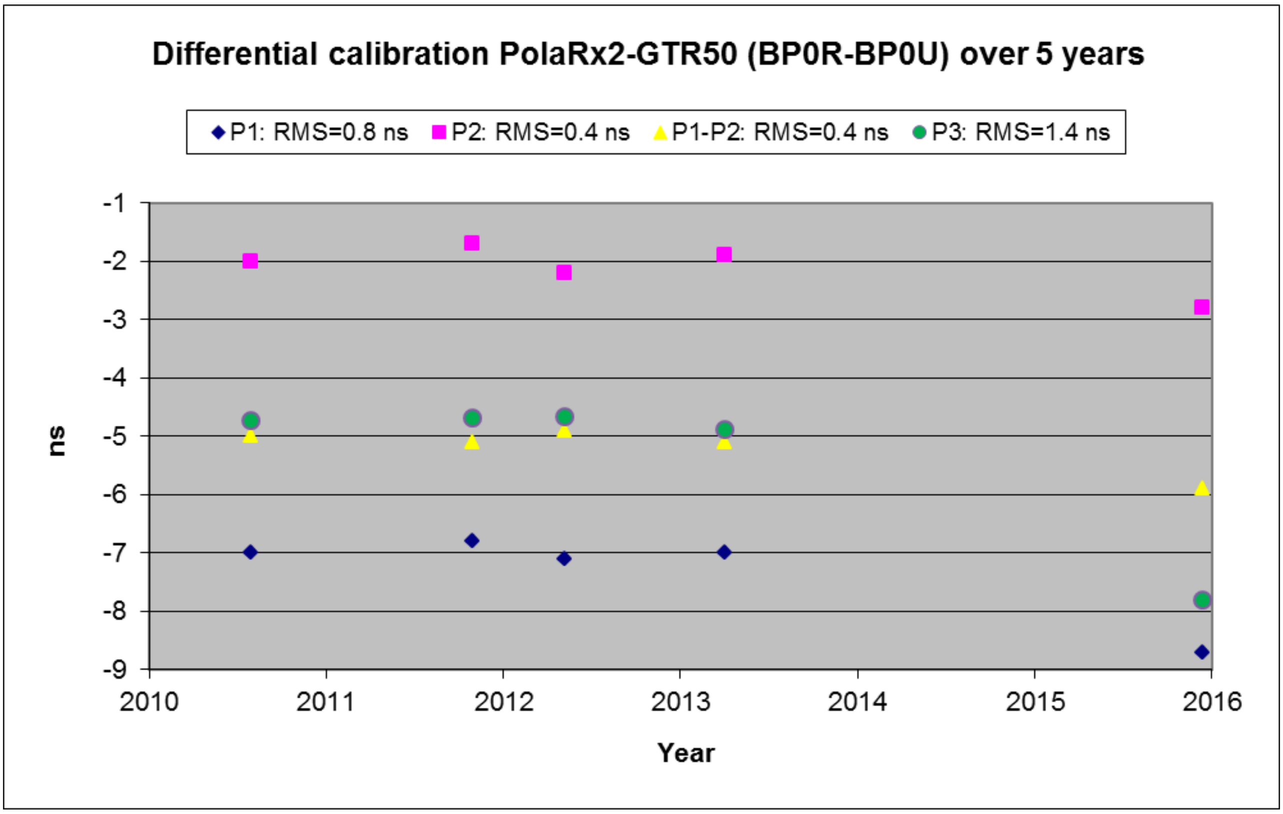

Figure 5: Differential calibration of the GTR50 BP0T vs. BP0R (results arbitrarily offset).

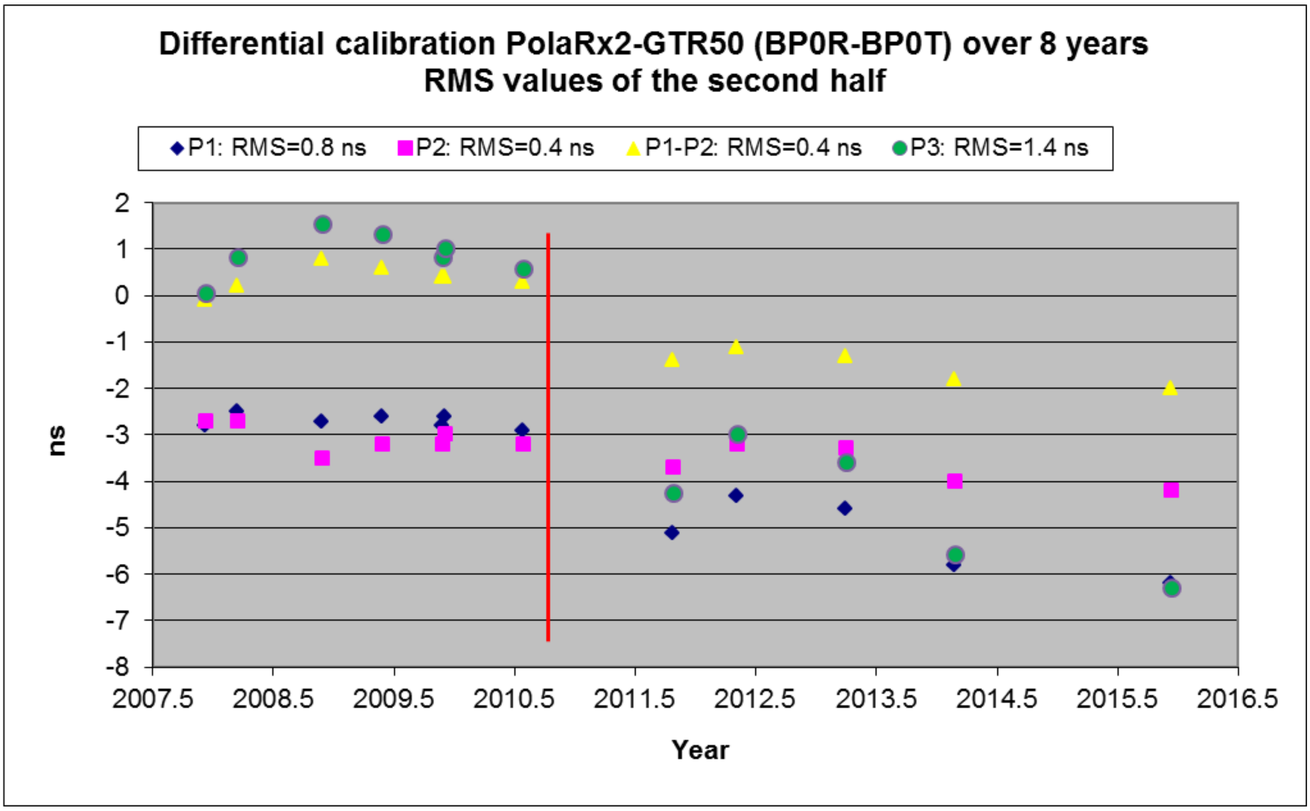

Figure 6: Differential calibration of the GTR50 BP0T vs. BP0R (results arbitrarily offset). Change of antenna cable in August 2010.