Between-satellite single-difference integer ambiguity resolution in the SPODS software

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Abstract

Between-satellite single-difference (BSSD) integer ambiguity resolution (IAR) in GPS/GNSS network solutions is proposed. The principle and key algorithm for BSSD IAR are presented. Validation experiments were carried out and the results show that the quality of satellite orbits, station coordinates and satellite clocks obtained with the BSSD approach was almost the same as that with the DD approach. It is also shown that the BSSD approach enjoyed slightly higher fixing ratio for both WL and NL ambiguities, and was superior in computation efficiency. It was verified that carrier-phase satellite clocks achieved has the ability to support IAR in PPP, just like that achieved with ZD IAR approach.

1. Introduction

In most of the existing GNSS analysis tools, such as the EPOS, Gispy, NAPEOS, GAMIT, Bernese, Panda, etc, DD approaches have been employed, leading to the fact that the products provided by the vast majority of the IGS ACs do not support PPP-IAR unless additional fractional cycle biases (FCBs) of satellites are provided. The only exception is that the GINS at the CNES adopts the ZD approach to routinely generate products, including carrier-phase clocks and WL satellite biases. The Satellite Positioning and Orbit Determination System (SPODS) developed at the Xi'an Research Institute of Surveying and Mapping has also employed a DD IAR approach slightly modified from Ge (2005) and recently developed a BSSD IAR approach in order to provide products supporting PPP-IAR.

2. Principle and Key algorithm for BSSD IAR

Unlike the DD Amb., the BSSD Amb. is not naturally of integer. Similar to the ZD IAR, in order to "waken up" the integer property of the rest BSSD ambiguities, datum BSSD Amb. have to be selected for each ambiguity-continuous arc of each satellite and compulsorily fixed to (the nearest) integers. This can be explained based on the integer nature of DD Amb., e.g. if there is a datum BSSD Amb. $\tilde{b}_{k,3}^{sl}$ with its WL and NL fixed to integers: $\tilde{N}_{k,w}^{sl}$ and $\tilde{N}_{k,n}^{sl}$, another BSSD Amb. $b_{r,3}^{sl}$, with which a DD Amb. $b_{rk,3}^{sl}$ can be formed, would theoretically gained the integer property and ambiguity fixing is possible. By analogy, more and more BSSD Amb. for the two satellite *s* and *l* are theoretically fixable as fixing procedure put forwards.

$$b_{r,3}^{sl} = b_{rk,3}^{sl} - \tilde{b}_{k,3}^{sl} = \frac{c}{f_i + f_j}\left(\frac{f_i}{f_i - f_j}\left(\tilde{N}_{k,w}^{sl} + N_{rk,w}^{sl}\right) + \left(\tilde{N}_{k,n}^{sl} + N_{rk,n}^{sl}\right)\right)$$

The BSSD ambiguity fixing procedures employed in the SPODS is quite similar to the DD approach as shown in Fig.1:

- **WL BSSD Amb. Fixing**
  - The FCBs of satellites are estimated. There are several well known method for this purpose.
  - With correction of satellite specified FCBs, WL Amb. fixing is conducted, just like that in PPP –IAR.
- **NL BSSD Amb. Fixing**
  - All possible BSSD Amb. with its WL successfully fixed in the previous step are formed and sorted increasingly according to their standard deviations and a group of independent DSSB Amb. is selected with the Kruskal algorithm.
  - A group of independent BSSD datum Amb. with minimum of standard deviations are selected, also with the Kruskal algorithm. Each ambiguity-continuous arc of each satellites should be represented by one and only on datum Amb.
  - Fixing the NL Amb. in a bootstrapping mode. Firstly, the datum BSSD NL Amb. is compulsorily fixed to (the nearest) integers, and then the remaining independent can be sequentially fixed to the nearest integer as for DD Amb. fixing.

NOTE: if any two epochs are connected by at least one ZD ambiguity, the two epochs is called "ambiguity-continuous".

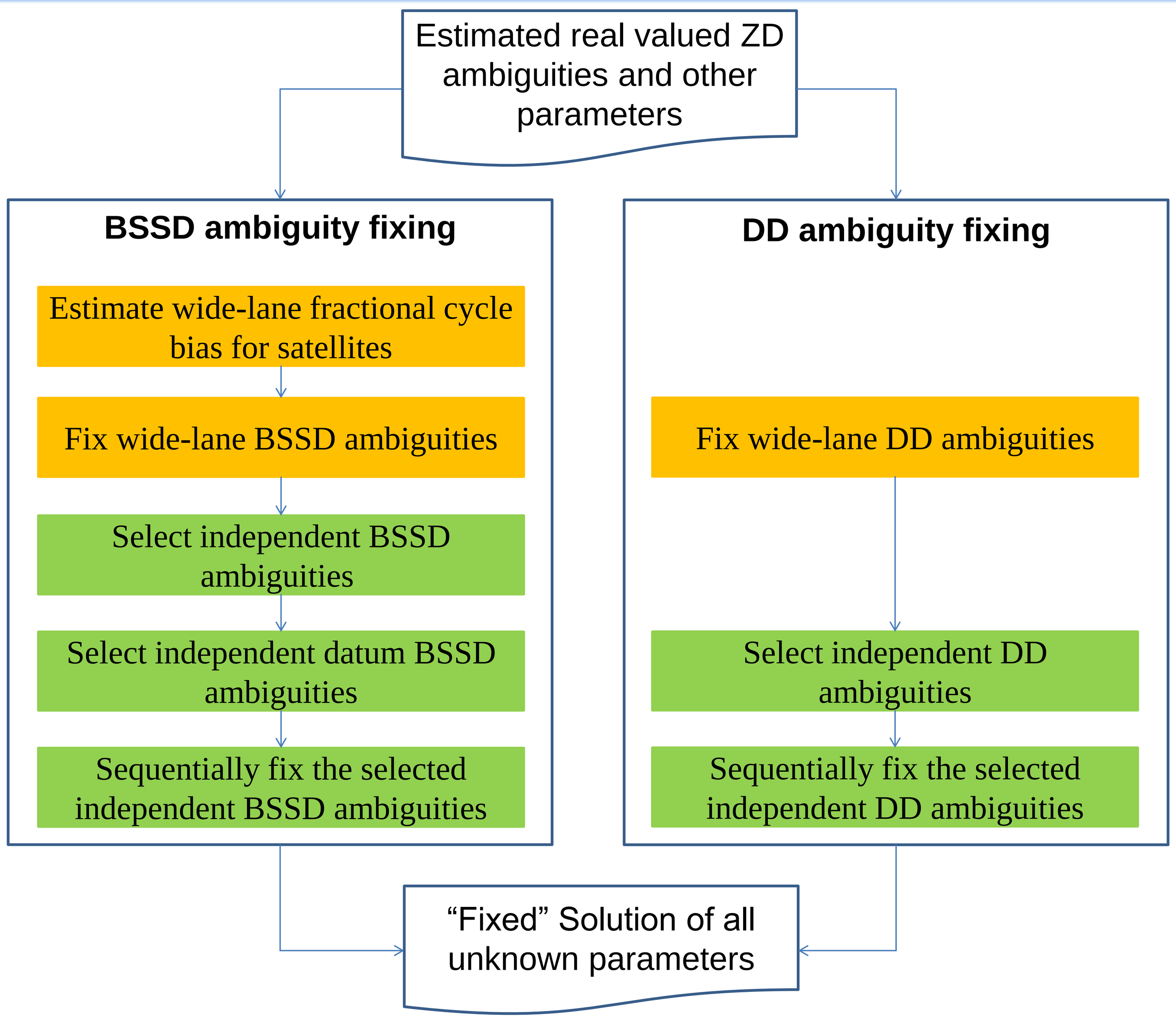

Fig. 1 Procedure for BSSD and DD ambiguity fixing

3. Validation Experiment

GPS data from IGS stations during day 300 to 365 of year 2016 were analyzed with both DD and BSSD IAR approach. The red point in Fig. 2 denote stations (~130) for network solution, while the others (~370) for rapid (30-min) PPP. The BSSD or DD WL or NL ambiguity is to be fixed only if its successful fixing probability is greater than 99.9% and the fractional part is less than 0.15 cycle.

- **The repeatability of the WL FCBs for most of the satellites is smaller than 0.04 cycle.**

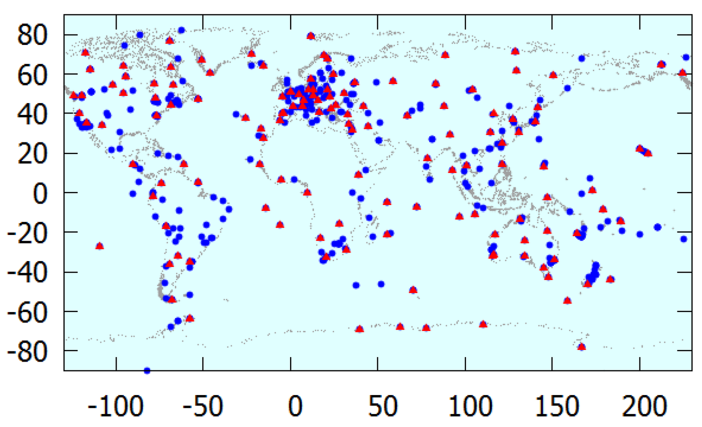

Fig.2 Distribution of IGS stations

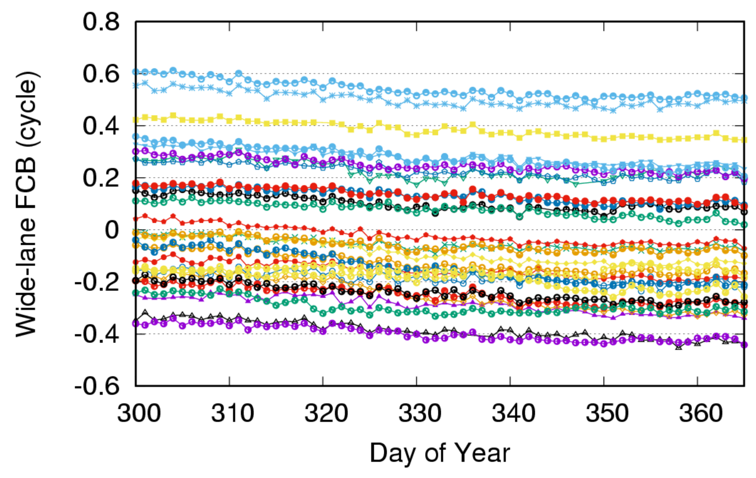

Fig.3 Series of WL satellite FCBs

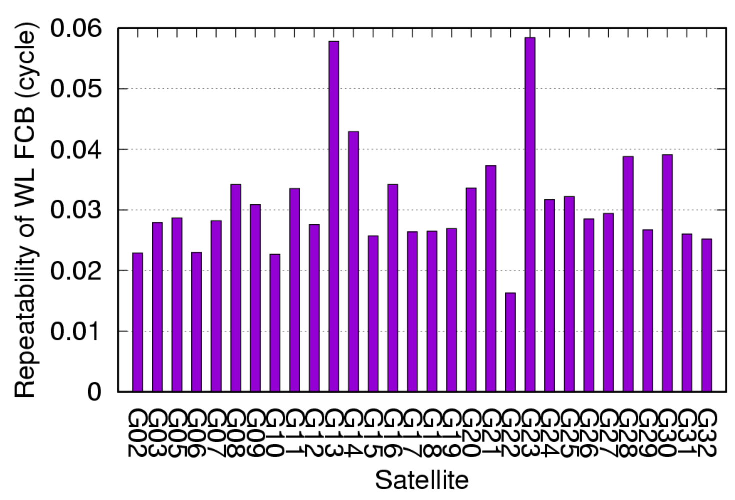

Fig.4 Repeatability of WL FCBs

- **Successful fixed ratio of BSSD WL or NL Amb. are both slightly higher.**
- **Computation time is reduce by 60.6%.**

IAR	WL	NL	TIME (min)
DD	92.0%	85.9%	66.7
BSSD	93.2%	88.8%	26.3

Tab.1 Averaged fixed ratio and computation time for DD/BSSD IAR

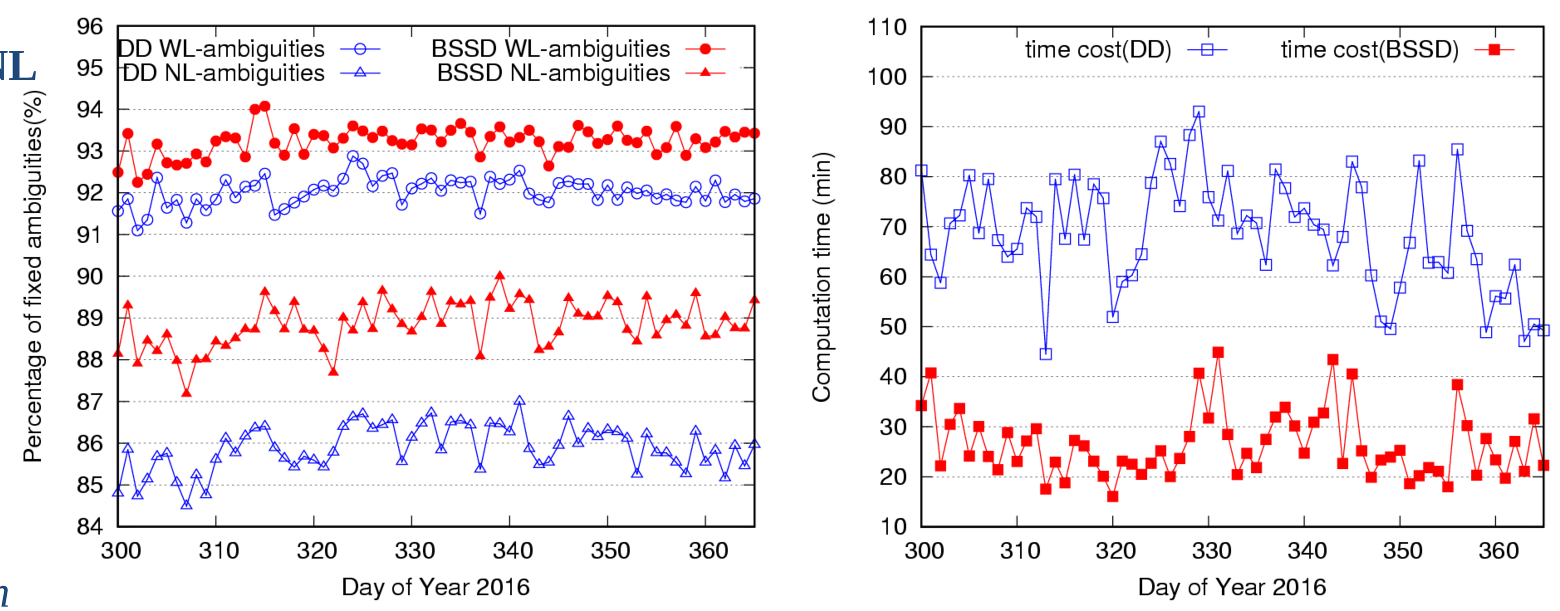

Fig.5 Percentage of fixed Amb. (left) and computation time (right) for IAR

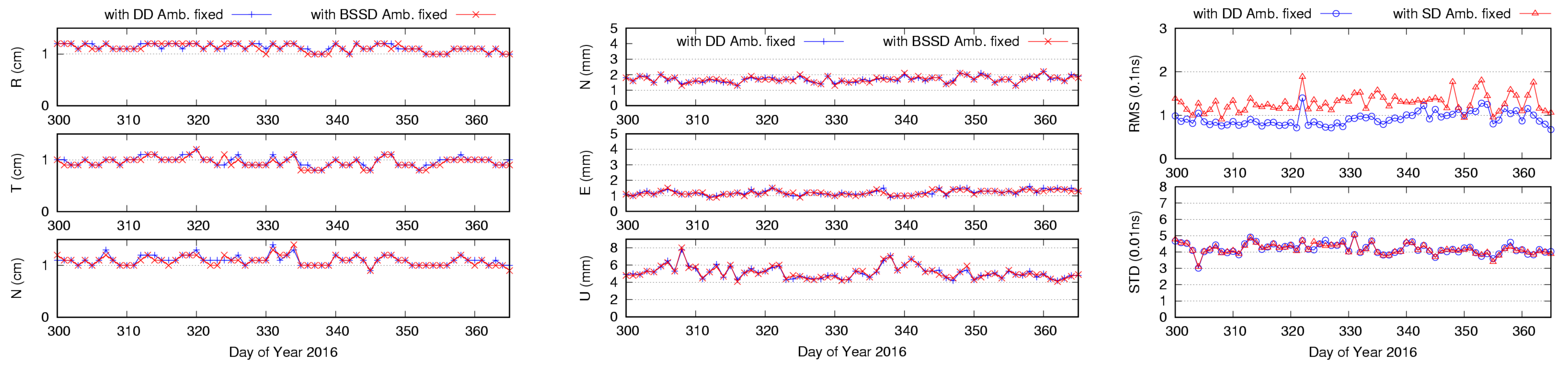

Fig.6 Daily RMSs of orbits (left), coordinates(middle) and clock (right) compared with IGS final products, as well as STDs for clocks

- **The RMSs for orbits, coordinates and STDs for clocks are nearly the same.**
- **The RMSs for clocks with BSSD IAR is much larger than that with DD IAR, because the integer datum in the former is biased from the latter as well as that of the IGS's.**

IAR	Orbits(mm)			Coordinates (mm)			Clocks(ns)	
	R	T	N	N	E	U	RMS	STD
DD	11.3	9.7	11.0	1.7	1.2	5.2	0.093	0.042
BSSD	11.2	9.6	10.9	1.7	1.2	5.2	0.130	0.042

Tab.2 Accuracy of station coordinates, satellite orbits and clocks

4. PPP-IAR Test

With satellite orbits, clock biases and FCBs obtained with the BSSD IAR approach, static PPP with 30-min data was carried out for the remaining ~370 IGS stations during day 330-336 of year 2016. Generally, there were 48 PPP solutions every day for each station. The LAMBDA method was applied to fix NL BSSD ambiguities after the WL Amb. has been fixed. Taking daily ambiguity-float PPP solutions as reference, deviations were calculated for each 30-min position estimates.

- **About 93% of the solutions with ≥4 BSSD Amb. Fixed, 80% of which with all BSSD Amb. fixed;.**
- **The accuracy (95%) of 30-min PPP solutions:**
  - **PPP(float) : 45.2mm, 129.6mm and 132.2mm;**
  - **PPP(fixed): 18.4mm, 27.3mm and 78.6mm;**

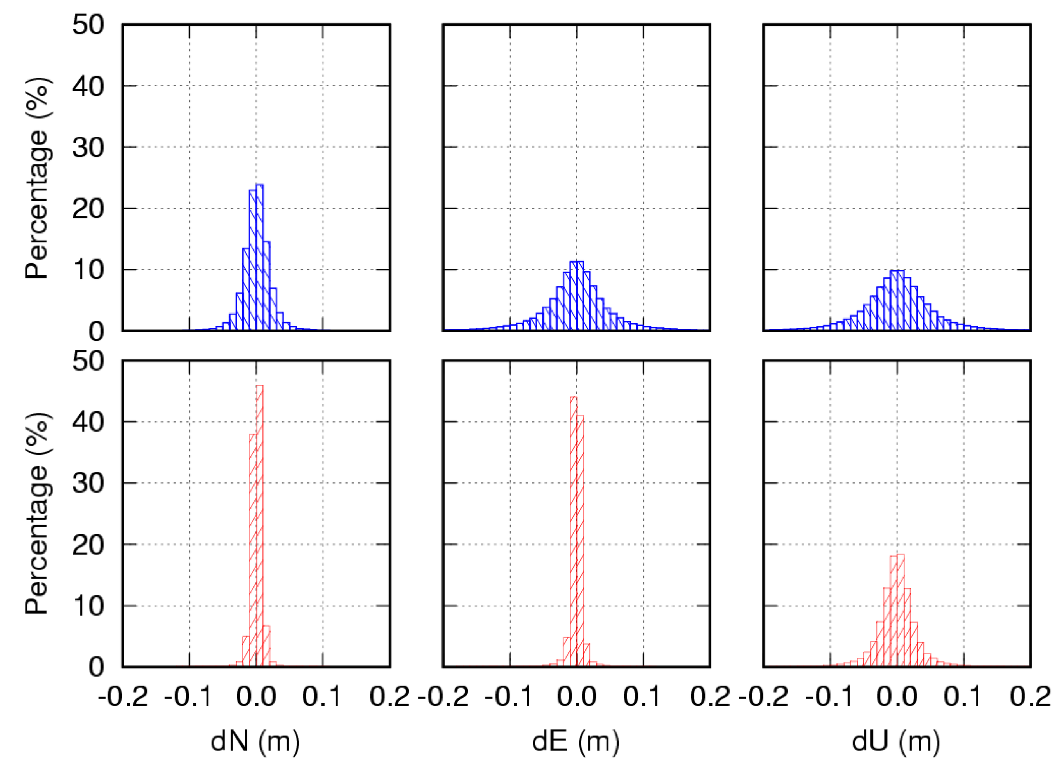

Fig.7 Histogram of position deviations with ambiguity-float (upper) and with ambiguity-fixed (bottom)

5. Conclusions

Network solutions with BSSD IAR is the same in quality with that using DD IAR approach. BSSD IAR enjoys the advantage that the clock products achieved would support IAR in PPP and the procedure is more efficient.

Acknowledgments

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Reference

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