

Revision of Paper TRET-2013-0065 Imprecise Datapath Design: An Overclocking Approach

Kan Shi, David Boland and George A. Constantinides

Reviewer 3

1. The first sentence of the abstract is completely devoid of context, and may be the worst sentence in the entire article, given its importance. A much more appropriate sentence is the start of Section 1, Paragraph 4.

Response: We have modified the first two sentences of the abstract, which now read as follows:

In this paper, we describe an alternative circuit design methodology when considering trade-offs between accuracy, performance and silicon area. We compare two different approaches that could trade accuracy for performance.

2. What are the chances that an entire design with all its complexities could be accelerated in this fashion? (i.e. Could the overall clock frequency be increased?) Imprecision may be tolerable in data, but is probably not tolerable in control.

Response: True. However the method described in this manuscript focuses on designing datapath instead of the control logic.

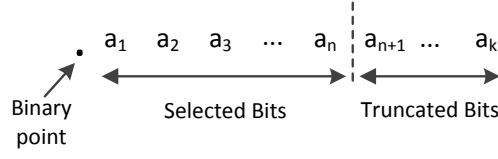
3. In Figure 1, you use μ , whereas in the text and in Equation 4, you use μ_c . The converse is true for Section 7.4 and equations (35), (36), and (37).

Response: Thanks. It should be μ_c in Fig.1 and Equations (35), (36) and (37). It has been fixed.

4. In Section 3.2, it would be helpful if you could illustrate or define your $[-1,1)$ fixed-point format. Do you number your bits from $k-1$ to 0 or from 0 to $k-1$?

Response: We meant that all numbers are normalized to fractional numbers within the range $[-1,1)$. The truncation process is illustrated in the figure below, which is not included in this manuscript due to the space limit. As seen in this figure, the original number embodies k fractional bits, while the truncated number embodies n fractional bits. Given that all bits are mutually independent and uniformly distributed, Equation (2) gives the mean value of the truncated bits.

We have modified the first sentence of the second paragraph of Section 3.2:



If the input signal of a circuit contains k fractional bits, truncation error occurs when the input signal is truncated from k bits to n bits.

5. In Section 3.3, for $A_i \neq B_i$ (Carry Propagation), you seem to be saying that $S_i = C_{i-1} = 0$. If $A_i \neq B_i$ then $A_i + B_i = 1$, but that tells us nothing unless we know C_{i-1} , and it is not necessarily 0 as you claim.

Response: Thanks for pointing this out. In this case it should be $C_{i-1} = 1$, because carry is propagated from bit $i - 1$ to bit i . Hence $S_i = A_i + B_i + C_{i-1} = 0$.

This statement is modified as follows:

Carry propagation: $A_i \neq B_i$, the carry propagates for this carry at bit i , and $C_{i-1} = 1$, $S_i = 0$.

6. For $A_i = B_i$ (either 0 or 1), there is no carry annihilation if their value is 1, and $S_i = C_{i-1} = 1$ seems to be a condition, not a consequence.

Response: This statement is only applied to determine the annihilation of an existing carry chain, i.e. $C_{i-1} = 1$. In this case if $A_i = B_i = 1$, the current carry chain is annihilated, meanwhile a new carry chain is generated. If $A_i = B_i = 0$, the current carry chain is annihilated but without generating a new chain. In both situations we have $S_i = C_{i-1} = 1$.

7. In 3.2, we have k as the full RCA length, and n as the truncated length. Compare that to n in 3.3.2 as the length of the non-truncated but overclocked RCA.

Response: In both sections, k is used to denote the word-length of the input signal, whereas n is the word-length of RCA.

8. Also in 3.3.2, the MSB is given as 2^n , instead of 2^0 as would be expected for the $[-1, 1)$ fixed-point format you mentioned.

Response: : 2^n is used here because 2^i is used in Equation (7). Nevertheless we agree it might be confusing to put 2^n here, and we have changed the second paragraph of Section 3.3.2 to look as follows:

For C_{tm} , correct results will be generated from bit S_t to bit S_{t+b-1} . Hence the absolute value of error seen at the output, normalized to the MSB, is given by (7), where \hat{S}_i and S_i denote the actual value and error-free value of outputs at bit i , respectively.

9. Still in 3.3.2, you seem to be saying that when a timing error occurs, none of the bits propagate. You assume $S_{t+b} = S_{t+b+1} = \dots = S_{t+m-2} = 0$ when there is no error, and $S_{t+b} = S_{t+b+1} = \dots = S_{t+m-2} = 1$ when there is an error. I think you are assuming the worst case, where no carry propagation occurs, so it is no surprise that you comment that the magnitude of overclocking error has no dependence on the length of carry chain m .

Response: The value of output S_i is determined based on the statements in Section 3.3.1. The assumption made here is that the internal signals are reset to zero before each computation. In this case, for carry propagation and timing error occurs, we have $S_i = A_i + B_i + C_{i-1} = A_i + B_i = 1$.

10. In 3.3.4, I see the $E_O = 2^{-b} - 2^{-n-1}$ result, but am puzzled by it. At the very least, I am not sure where the $-b$ exponent is coming from, since (8) defines $e_{tm} = 2^{t+b-n}$.

Response: We would like to derive Equation (14) as follows:

$$\begin{aligned}
E_O &= \sum_t \sum_m P_{tm} \cdot e_{tm} \\
&= \sum_{t=0}^{n-b} 2^{t+b-n} \cdot \left(\sum_{m=b+1}^{n-t} (1/2)^{m+1} + (1/2)^{n-t+1} \right) \\
&= \sum_{t=0}^{n-b} 2^{t+b-n} \cdot \left((1/2)^{b+1} - (1/2)^{n-t+1} + (1/2)^{n-t+1} \right) \\
&= \sum_{t=0}^{n-b} 2^{t+b-n} \cdot 2^{-b-1} = \sum_{t=0}^{n-b} 2^{t-n-1} \\
&= 2^{-n-1} \cdot (2^{n-b+1} - 1) \\
&= 2^{-b} - 2^{-n-1}
\end{aligned}$$

The detailed process is not included in the manuscript due to the space limit.

11. The third and fourth paragraphs of Section 5.1 mention the 4-stage CSA, but Figure 4 does not show any data for a 4-stage CSA.

Response: Thanks. In the third paragraph of Section 3.1, it should be the 3-stage CSA. Therefore the last sentence of this paragraph is revised as:

Although the CSA with 3 stages is best for some frequencies, the overclocked RCA is still the optimum design when high operating frequencies are applied.

The 4-stage CSA is introduced in the fourth paragraph and Fig. 5 and Fig. 6, where we consider a variety of area constraints. Ideally with larger available area, CSA with more stages will be included in both Fig. 5 and Fig. 6. However the general trend will be similar. In previous paragraphs of this section, we only use 2-stage CSA and 3-stage CSA as examples to illustrate the design method. We have clarified this point by adding

the following sentence to the fourth paragraph of Section 3.1:

We implement CSA with all possible stage numbers within the given area specification.

12. In the experimental setup, I would be curious to know whether you used any particular constraints on the circuits-under-test to enhance their chances of success.

Response: Actually no specific constraints are applied, except the global clock constraint.

13. May I assume that your figures will be colorized?

Response: Yes, Fig. 3, Fig. 4 and Fig. 10 will be colorized.

14. An incomplete list of spelling or grammar or punctuation comments.

Response: Thanks, they have been revised.