Synchronizer Circuit Performance

David Kinniment
Alex Bystrov
Alex Yakovlev

University of Newcastle upon Tyne, UK

Outline of presentation

- Current state of Synchroniser design
  - Need for high performance
  - Unsolved problems
- Linear modelling predictions
- Circuit performance
  - MUTEX
  - Jamb latch
  - Modified Q-Flop
- Noise measurements
- Conclusions
Generic Synchronizer

- Handles self timed to synchronous interfaces and vice-versa
- Supports synchronous to synchronous interfaces

\[ MTBF = \frac{e^{t/\tau}}{T_w \cdot f_1 \cdot f_2} \]

State of the art

- You require about 35 $\tau$s in order to get the MTBF out to about 1 century. (That’s for 1 synchronizer)
- Each typical static gate delay is equivalent to about 5 $\tau$s in a properly designed synchronizing flop. (Latency of more than a clock cycle)
- You must assume a ‘malicious’ input to the synchronizer. Nevertheless, this only adds about 5 $\tau$s to the delay.
- Jamb latch is the preferred circuit
Simple jamb latch

Given a uniform distribution of Clock-Data overlaps
We measure the number of events with a given propagation delay

Histogram

0.6mV is about the level of thermal noise on a node
Some questions

- Is the Jamb latch the best circuit for a synchronizer?
- MTBF formula does not appear to hold throughout, so does the theory need to be changed?
- Does thermal noise need to be taken into account?

Linear Model

- Simple linear model leads to two exponentials
- $\tau_a$ is convergent, $\tau_b$ is divergent

$$\tau_1 = \frac{C_1 R_1}{A}, \tau_2 = \frac{C_2 R_2}{A}$$

$$0 = \tau_1 \frac{d^2 V_1}{dt^2} + \left(\tau_1 + \tau_2\right) \frac{dV_1}{dt} + \frac{1}{A^2 - 1} V_1$$

$$V_1 = K_a e^{\tau_a t} + K_b e^{\tau_b t}$$
Model Time Response

Vout

Volts

ps

High Start

1.75V

1.8

1.6

1.4

1.2

0 100 200 300 400 500

Probability of an event occurring within 10ps of a particular output time

Histogram of events

Model Response

Events

Output time, ns

Low Start

High Start

Slope

ACiD Workshop Feb 12 -13
MUTEX with low threshold output

- Starts high, needs to go low to give output
- Threshold about 100 mV low
- Same case as low start, high threshold in theory

Classical MUTEX with filter

- Needs more than 1V difference to give output
- Slower
Some measurements

<table>
<thead>
<tr>
<th></th>
<th>τ between 30-1ps</th>
<th>τ below 0.01ps</th>
<th>Initial slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical low threshold</td>
<td>59</td>
<td>96</td>
<td>61%</td>
</tr>
<tr>
<td>Simulated low threshold</td>
<td>78</td>
<td>131</td>
<td>60%</td>
</tr>
<tr>
<td>Simulated with filter</td>
<td>122</td>
<td>127</td>
<td>96%</td>
</tr>
<tr>
<td>Measured with filter</td>
<td>99</td>
<td>106</td>
<td>93%</td>
</tr>
</tbody>
</table>

Jamb latch

- Data high, then Clock low, measure from clock
- Two types of Jamb latch simulated, τ = 95 ps
Waveforms

- Node B starts low, needs to go high
- Node A starts low, needs to go low
- Final clock edge also affects node voltage

Jamb Node B, data last

- Measure from early clock edge, so time appears longer for wide pulses (frequent events)
- Final negative data edge delays some events because of miller effect (capacitance coupling Node A to data input)
Faster synchroniser

- Large drive transistors needed for Jamb latch
- Can use small drive devices if latch is not initially regenerative
- Similar to Molnar’s Q-Flop

Low value $\tau$

- 75 ps $\tau$
- Needs conventional slave to hold state
- Static delay is longer because of low drive
Noise measurements

- Hard to control input edge timing to 0.1ps
- Easier to control DC inputs to 1 mV
- Change input voltage slowly, and observe % of High outputs

Noise results

- Noise is 3.3 mV RMS at input
- Equivalent to about 1 mV between Nodes B0 and B1
- Theory says thermal noise should be 0.73 mV

\[ \sqrt{\frac{4kT}{C}} \]
Noise point

Does noise affect $\tau$?

- Probability of escape from metastability does not change with gaussian noise (Couranz and Wann 1975)
Conclusions

- The Jamb latch is not necessarily the fastest Synchronizer
- Q-Flop and Jamb are similar at 1 ns (11τ, or 14τ)
- Differing τ in the early part of the histogram can be explained by the initial conditions.
- For metastability times of 6-8τ or more, the output becomes non-deterministic, and an individual output time no longer depends primarily on the inputs.