

Motivation

- Most of the earlier probabilistic approaches for gate level switching power estimation neglects glitch power, which is caused by signal changes in the transient interval.
- For other approaches where glitch power was included, *glitch filtering effect* of gates (i.e. glitches with pulse width less than the gate inertial delay will be "filtered out" by the gate) has seldom been considered.
- Glitch filtering effect can dramatically change the switching activity of gates. An accurate modeling of this effect is essential in switching power estimation.

Backgrounds and Definitions

- Transition density** $D(x)$, average number of transitions a logic signal x makes in a unit time (one clock cycle) [1].
- Probabilistic simulation** [2,3]:
 - Probability waveform, a sequence of *signal probabilities* and *transition probabilities* over signal transition interval.
 - Signal probability $sp_n(t)$, probability of node n having logic 1 at time t .
 - Transition probability $P_n^s(t)$, probability that node n has a logic transition state s ($s \in \{00, 01, 10, 11\}$) at time t .

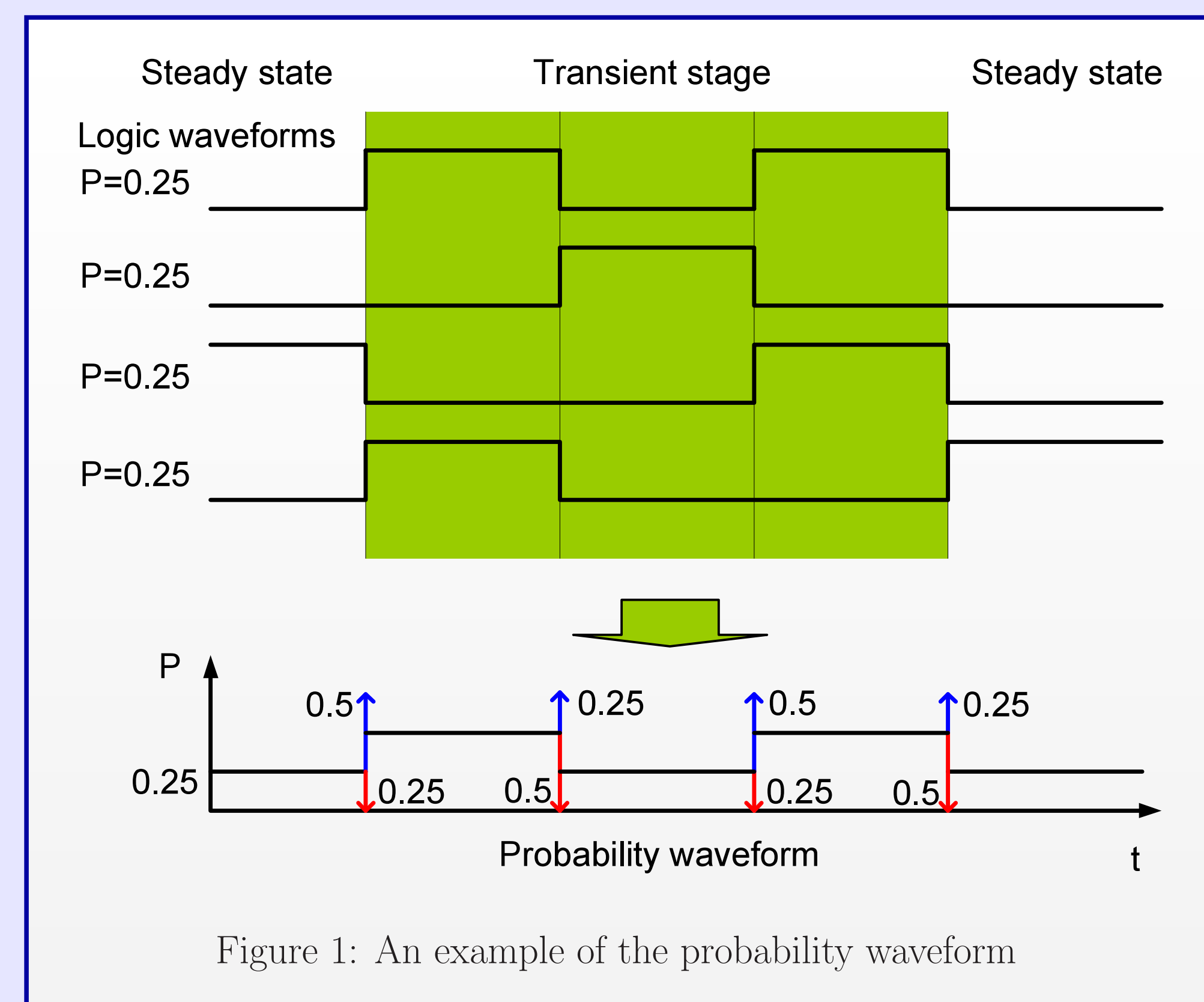


Figure 1: An example of the probability waveform

- Tagged probabilistic simulation (TPS)** [4]:
 - Tagged probability waveform, partition of a probability waveform according to the steady state signal values, i.e., tagged waveform $w_n^{00}, w_n^{01}, w_n^{10}, w_n^{11}$.
 - Signal probability, $sp_n^{xy}(t)$, probability of node n having logic 1 at time t on waveform w_n^{xy} ($x, y \in \{0, 1\}$).
 - Transition probability, $P_{n,xy}^s(t)$, probability that node n has a logic transition state s ($s \in \{00, 01, 10, 11\}$) at time t on waveform w_n^{xy} .
 - Spatial correlation coefficient, $\omega_{a,b}^{xy,wz}$, exact spatial correlations approximated by the *macroscopic spatial correlations* between steady state signal values (tags).

Dual-Transition Probability

Original glitch filtering in TPS:

- Substraction of glitch probability from transition probabilities on the tagged probability waveforms.
- Limitations:
 - Imprecise estimation of glitch probabilities.
 - Can't filter glitches coming from single input.

A new measure of Dual-Transition Probability:

- Find the exact condition for a pulse, knowing that each signal has 4 possible states at each time instance t .
- In probability waveform
$$P_c^{01,10}(t_1, t_2) \equiv P\{c \text{ has } \uparrow \text{ at } t_1 \text{ and } \downarrow \text{ at } t_2\} = P\{(a, b) \text{ at } t_1 \text{ is } (01, 11) \text{ or } (11, 01) \text{ or } (01, 01) \text{ and } (a, b) \text{ at } t_2 \text{ is } (10, 11) \text{ or } (11, 10) \text{ or } (10, 10)\} \quad (1)$$
- For the above two-input AND gate, $P_c^{01,10}(t_1, t_2)$ is a sum of 9 product terms. Example term: $P_a^{01,10}(t_1, t_2)P_b^{11,11}(t_1, t_2)$ as shown in Figure 2.

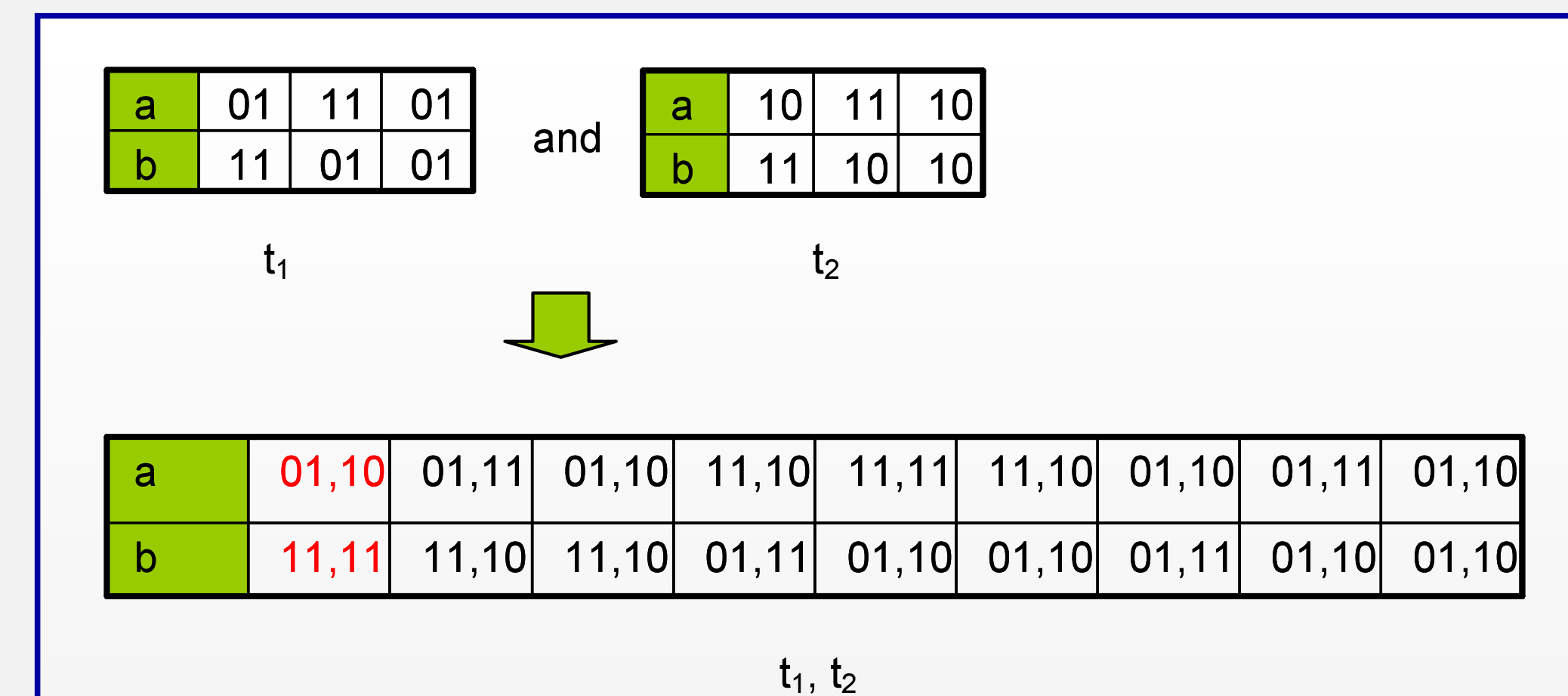


Figure 2: Dual-transition probability for a two-input AND gate.

- In TPS, use macroscopic spatial correlations to approximate spatial correlations:

$$P_{c,(xy,wz)}^{01,10}(t_1 + d, t_2 + d) = \sum_{i=1}^3 \sum_{j=1}^3 P_{a,xy}^{sa1_i,sa2_j}(t_1, t_2) P_{b,wz}^{sb1_i,sb2_j}(t_1, t_2) \omega_{a,b}^{xy,wz} \quad (2)$$

where d is gate delay, $x, y, w, z \in \{0, 1\}$, $(sa1_i, sb1_i) \in \{(01, 11), (11, 01), (01, 01)\}$, $(sa2_j, sb2_j) \in \{(10, 11), (11, 10), (10, 10)\}$

New Glitch Filtering Method

Propagation of dual-transition probabilities:

- Propagated from primary inputs towards output.
- For primary inputs, where transition only occur at time 0, the dual-transition probabilities are derived by the transition probability at PIs (or zero).

Dual-transition glitch filtering:

- Can be applied to both probabilistic simulation and TPS.
- For a two input AND gate, after the waveform propagation,

$$\begin{aligned} P_{c,(xy,wz)}^{01} (t_1) - &= P_{c,(xy,wz)}^{01,10} (t_1, t_2) \\ P_{c,(xy,wz)}^{10} (t_2) - &= P_{c,(xy,wz)}^{01,10} (t_1, t_2) \\ P_{c,(xy,wz)}^{10} (t_1) - &= P_{c,(xy,wz)}^{10,01} (t_1, t_2) \\ P_{c,(xy,wz)}^{01} (t_2) - &= P_{c,(xy,wz)}^{10,01} (t_1, t_2) \end{aligned} \quad (3)$$

for each pair of t_1, t_2 , where $t_2 - t_1 < d$

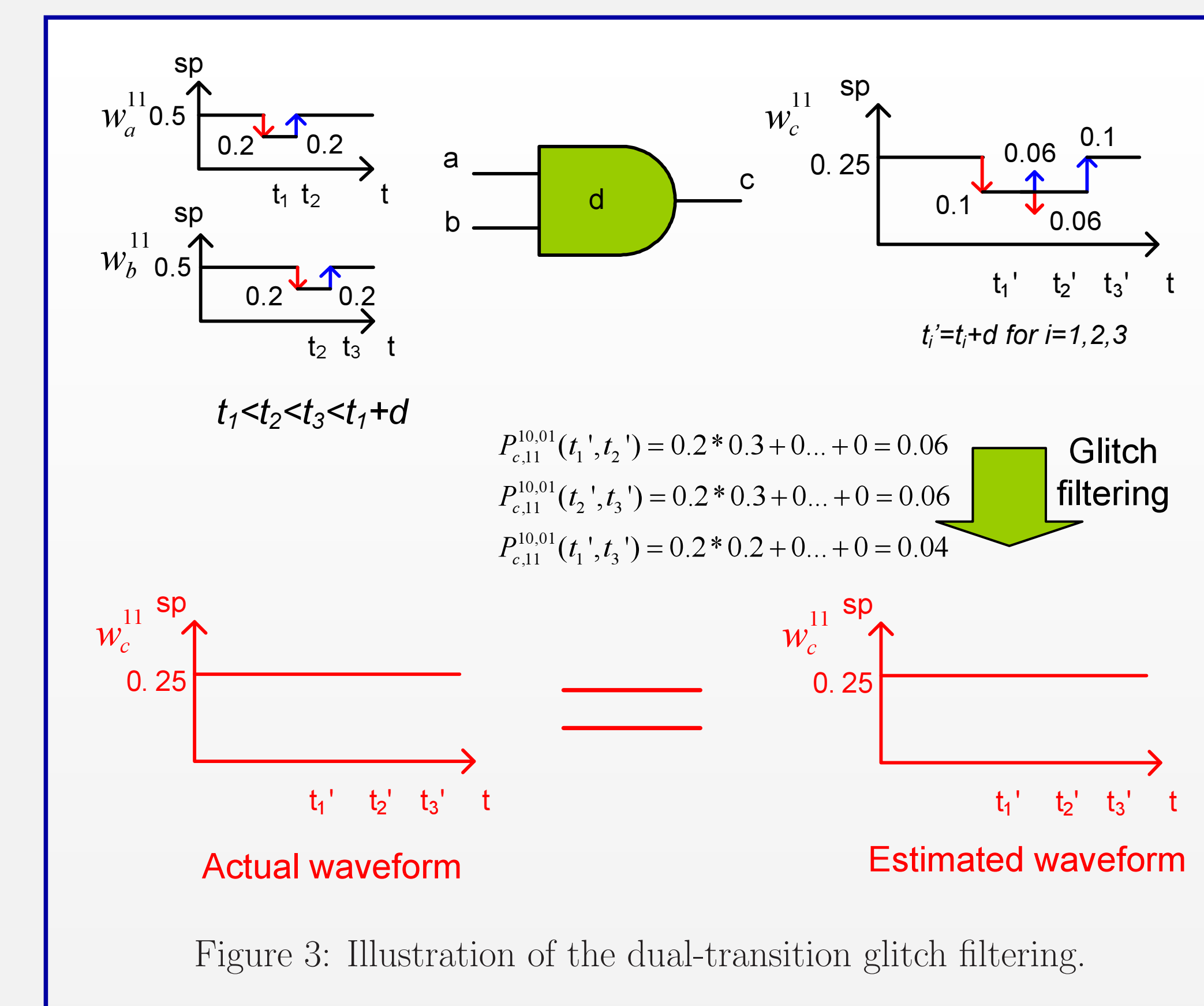


Figure 3: Illustration of the dual-transition glitch filtering.

Update dual-transition probabilities:

- No two transitions can occur simultaneously within gate delay d after the filtering.
- Dual-transition correlation updated accordingly after the filtering.

Experimental Results

- Implemented in both probabilistic simulation (**ProSim+DT**) and TPS (**TPS+DT**).
- Compared to results by event driven logic simulations, assuming spatial and temporal independence for PIs.
- ISCAS'85 benchmark circuits:**
 - Gate delay proportional to fanouts, with input signal probability of 0.5.
 - E_{avg} : average of node errors (percentage errors with respect to average node power obtained from logic simulation).
 - σ : standard deviation of node errors, E_{tot} : percentage error of total power.

Estimation accuracy:

- Large error for ProSim+DT due to negligence of spatial correlations.
- TPS+DT has up to 29% improvement on E_{tot} ; e.g. c432.
- TPS+DT gives a more consistent estimation in terms of average and maximum errors.
- TPS+DT gives larger error for certain circuits
 - Estimation accuracy is jointly decided by TPS and DT. Therefore, effectiveness of DT is limited by the inherent errors in TPS.

Table 1: Switching power comparison for a ISCAS'85 benchmark circuits.

Circuits	ProSim+DT			TPS			TPS+DT		
	E_{avg} (%)	σ (%)	E_{tot} (%)	E_{avg} (%)	σ (%)	E_{tot} (%)	E_{avg} (%)	σ (%)	E_{tot} (%)
c17	5.8	7.8	0.7	2.3	2.6	0.1	2.3	2.6	0.1
c432	14.7	17.3	8.5	29.9	38.8	35.8	9.5	11.8	6.5
c499	6.2	11.6	6.6	6.8	14.0	7.0	3.6	8.2	0.6
c880	11.2	18.3	7.3	8.3	15.3	1.6	8.0	15.7	5.2
c1355	16.8	21.5	18.3	24.2	31.6	32.9	5.8	11.2	5.4
c1908	21.9	33.8	19.7	15.0	23.1	4.1	17.7	27.9	11.2
c2670	20.6	29.7	15.0	16.6	29.8	7.2	16.7	28.3	9.9
c3540	16.6	36.3	10.0	13.8	26.3	9.8	10.3	25.6	2.4
c5315	20.2	40.1	17.2	11.8	24.4	2.3	13.4	31.5	10.1
c6288	29.6	29.9	26.4	27.4	27.5	32.1	15.7	18.8	4.1
c7552	21.6	39.9	16.4	14.5	27.5	3.2	14.8	31.4	7.8
Avg.	16.8	26.0	13.3	15.5	23.7	12.4	10.7	19.4	5.7
Max.	29.6	40.1	26.4	29.9	38.8	35.8	17.7	31.5	11.2

Computation costs:

- TPS+DT is 2-3 times faster than the logic simulation over 40K input vectors.
- ProSim+DT is 20-30 times faster while original TPS is 2 order of magnitude faster than logic simulation.
- Computation cost for dual-transition probabilities is a little expensive.
- ProSim+DT is faster since it only propagates one probability waveform.

Conclusions

- We propose an improved glitch filtering method with a new concept of dual-transition probability.
- The new method improved the power estimation accuracy of original TPS, which is significant for certain circuits.
- The new method improved the power estimation consistency over different circuits.
- The effectiveness of the new method is still limited by the inherent errors in TPS. Further improvements of TPS itself are under investigation.

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