Contents

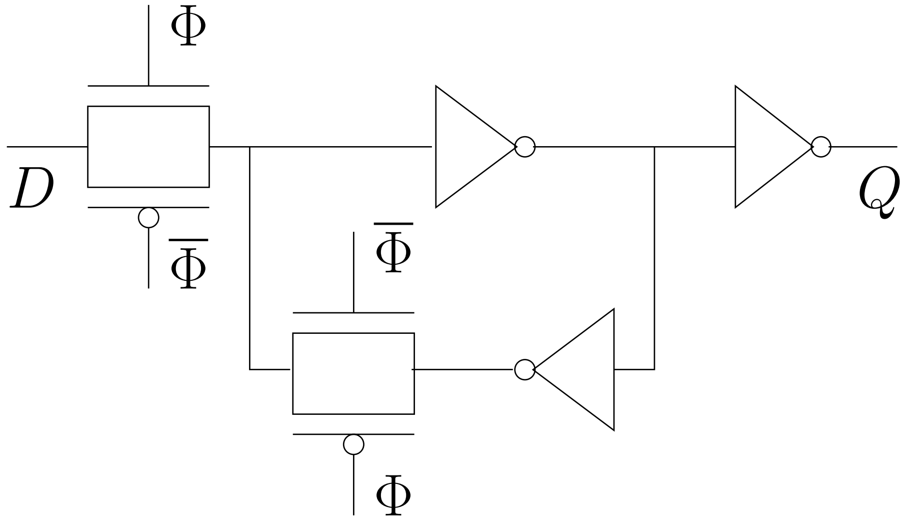

Figure 1: The pass gate latch circuit

0.1 Verification of Latch Circuit

Latch is an electronic circuit (a bistable multivibrator) that has two stable states and thereby is capable of serving as one bit of memory. Figure 1 shows the *pass gate latch* that we want to verify.

0.1.1 Specification

For a general latch, it is required that the input should be stable when the clock falls. For the output, it should be stable when the clock is low. Figures 2 and 3 shows the specification of input and output.

0.1.2 Simulation

The brockett annulus of d, q, x and $\bar{\Phi}$ are shown in figures 4, 5, 6 and 7.

The value of x signal in different states (brockett regions) is shown in figure 8.

0.1.3 Verification

Computation Order

For the latch circuit, there are one clock signal and one input signal specified as an brockett annulus. Each annulus has four regions, thus there are 16 combinations as shown in figure 9.

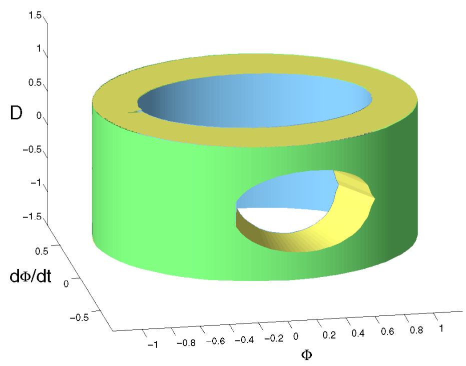

Figure 2: The input specification

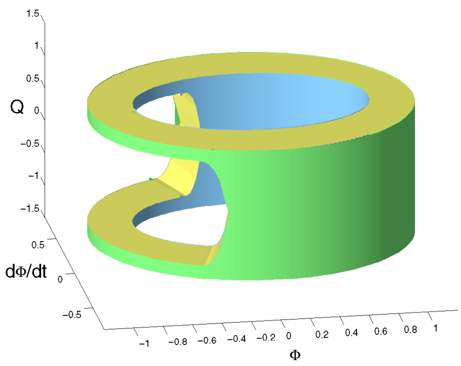

Figure 3: The output specification

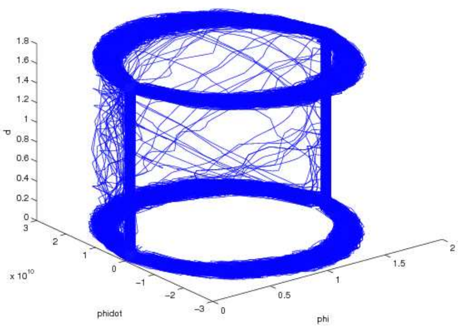

Figure 4: The input d specification

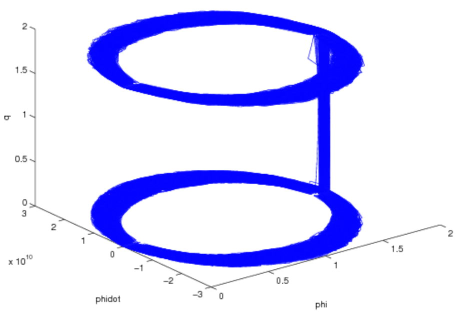

Figure 5: The output q specification

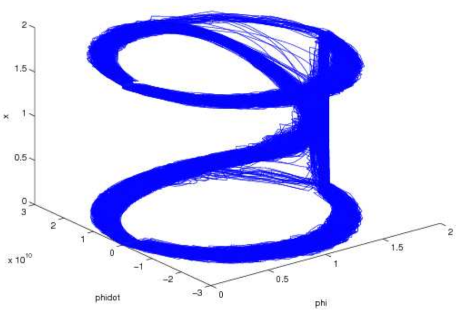

Figure 6: The x signal specification

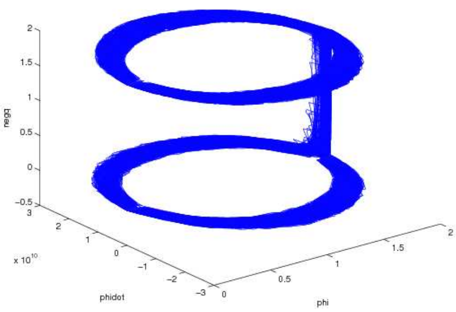

Figure 7: The $\bar{q}$ signal specification

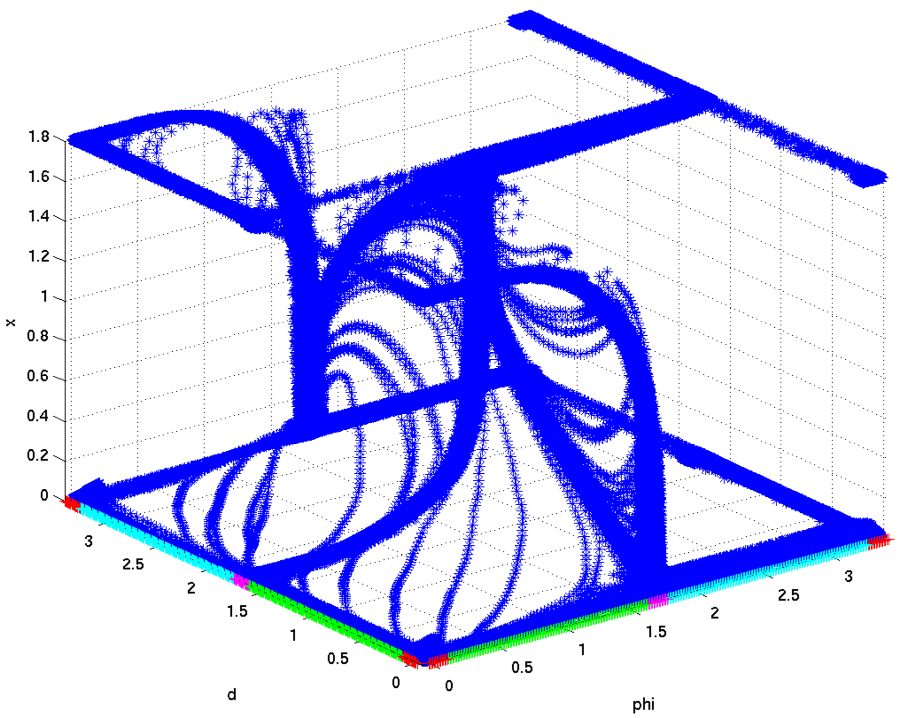

Figure 8: The x signal in different brockett region of simulation

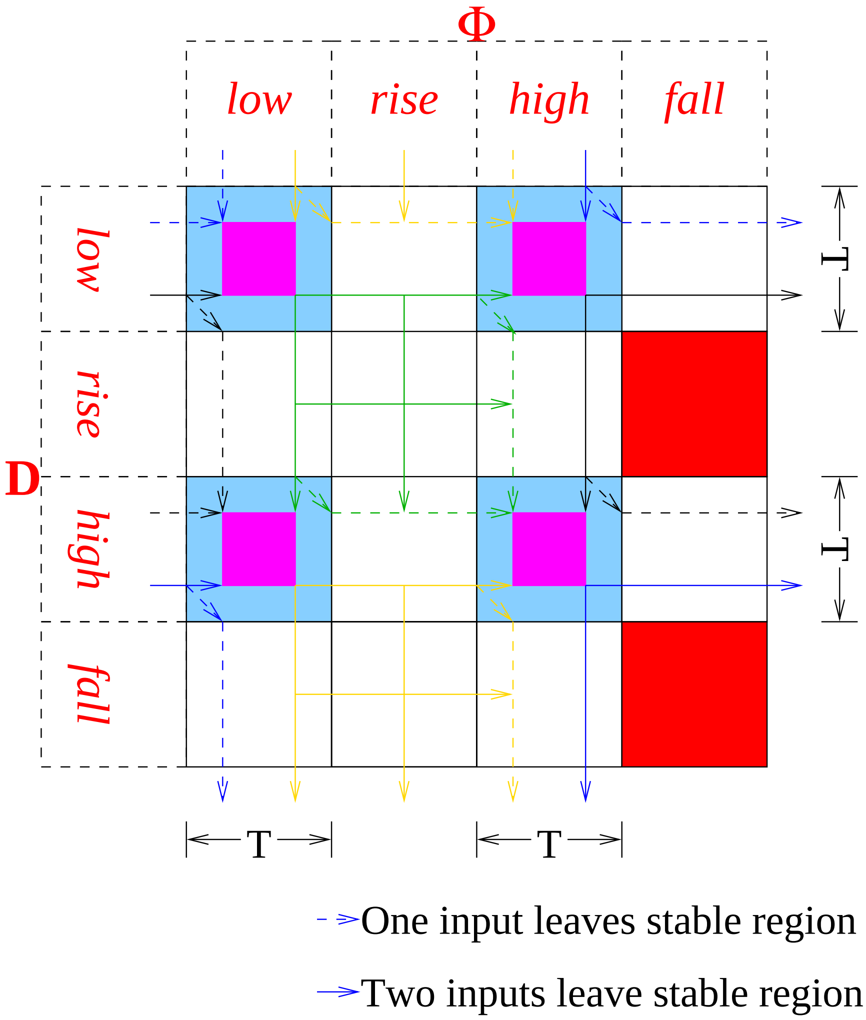

Figure 9: The new state transition diagram

And our computation order is:

1. Given initial state, compute the reachable space in parallel.
   (a) Start from $\langle low, low\rangle$ with $x = low$.
   (b) Start from $\langle low, low\rangle$ with $x = high$.
   (c) Start from $\langle low, high\rangle$ with $x = low$.
   (d) Start from $\langle low, high\rangle$ with $x = high$.
   (e) Start from $\langle high, low\rangle$ with $x = low$.
   (f) Start from $\langle high, low\rangle$ with $x = high$. (same with above)
   (g) Start from $\langle high, high\rangle$ with $x = low$.
   (h) Start from $\langle high, high\rangle$ with $x = high$. (same with above)
2. Verify the initial region and prove the space is invariant
   (a) Use result from 1e 1f, 1c, to verify the initial region of item 1a.
   (b) Use result from 1g 1h, 1d, to verify the initial region of item 1b.
   (c) Use result from 1e 1f, 1a, to verify the initial region of item 1c.
   (d) Use result from 1g 1h, 1b, to verify the initial region of item 1d.
   (e) Use result from 1a 1c, to verify the initial region of item 1e.
   (f) Use result from 1b 1d, 1g, 1h, to verify the initial region of item 1f.
   (g) Use result from 1a 1c, 1e, 1f to verify the initial region of item 1g.
   (h) Use result from 1b 1d to verify the initial region of item 1h.

Result

The result is shown in figure 10, 11, 12, 13.

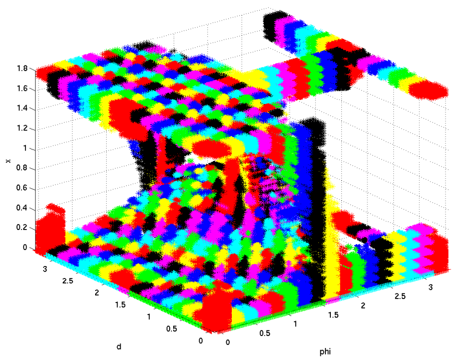

Figure 10: xbrock v5

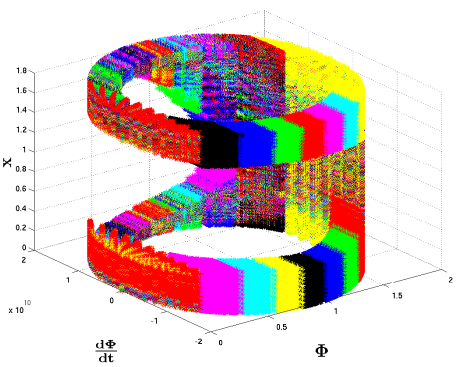

Figure 11: xspec v5

The initial and verified face is

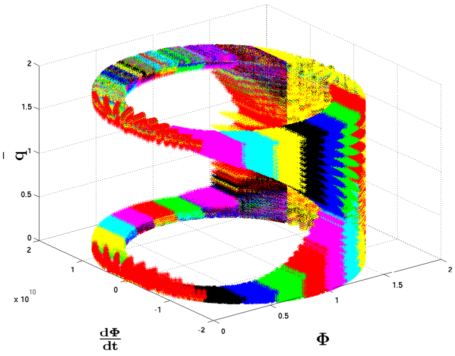

Figure 12: nqspec v5

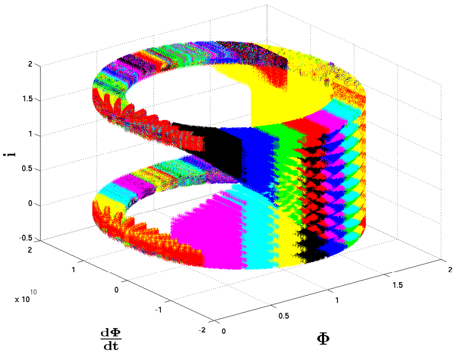

Figure 13: ispec v5

face	low2high		high2low	
	inital	result	initial	result
clk(1,1)	$\begin{bmatrix} 0.2 & 0.2 \\ 0.0 & 0.2 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \end{bmatrix}$	$\begin{bmatrix} 0.2 & 0.2 \\ 0.0 & 0.2 \\ 1.7990 & 1.8 \\ 0.0 & 0.0016 \\ 1.8 & 1.8 \\ 0.0 & 0.0008 \end{bmatrix}$	$\begin{bmatrix} 0.2 & 0.2 \\ 0.0 & 0.2 \\ 1.7 & 1.8 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \\ 1.7 & 1.8 \end{bmatrix}$	$\begin{bmatrix} 0.2 & 0.2 \\ 0.0 & 0.2 \\ 1.7987 & 1.8 \\ 1.7919 & 1.8 \\ 0.0 & 0.0 \\ 1.7958 & 1.8 \end{bmatrix}$
data(1,1)	$\begin{bmatrix} 0.0 & 0.2 \\ 0.2 & 0.2 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \end{bmatrix}$	$\begin{bmatrix} 0.0 & 0.2 \\ 0.2 & 0.2 \\ 1.7990 & 1.8 \\ 0.0 & 0.0016 \\ 1.8 & 1.8 \\ 0.0 & 0.0008 \end{bmatrix}$	$\begin{bmatrix} 0.0 & 0.2 \\ 0.2 & 0.2 \\ 1.7 & 1.8 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \\ 1.7 & 1.8 \end{bmatrix}$	$\begin{bmatrix} 0.0 & 0.2 \\ 0.2 & 0.2 \\ 1.7987 & 1.8 \\ 1.7919 & 1.8 \\ 0.0 & 0.0 \\ 1.7958 & 1.8 \end{bmatrix}$
clk(1,9)	$\begin{bmatrix} 0.2 & 0.2 \\ 1.6 & 1.8 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \end{bmatrix}$	$\begin{bmatrix} 0.2 & 0.2 \\ 1.6 & 1.8 \\ 1.7989 & 1.8 \\ 0.0 & 0.0025 \\ 1.8 & 1.8 \\ 0.0 & 0.0013 \end{bmatrix}$	$\begin{bmatrix} 0.2 & 0.2 \\ 1.6 & 1.8 \\ 1.7 & 1.8 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \\ 1.7 & 1.8 \end{bmatrix}$	$\begin{bmatrix} 0.2 & 0.2 \\ 1.6 & 1.8 \\ 1.7991 & 1.8 \\ 1.7937 & 1.8 \\ 0.0 & 0.0 \\ 1.7966 & 1.8 \end{bmatrix}$
data(1,9)	$\begin{bmatrix} 0.0 & 0.2 \\ 1.6 & 1.6 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \end{bmatrix}$	$\begin{bmatrix} 0.0 & 0.2 \\ 1.6 & 1.6 \\ 1.7989 & 1.8 \\ 0.0 & 0.0025 \\ 1.8 & 1.8 \\ 0.0 & 0.0013 \end{bmatrix}$	$\begin{bmatrix} 0.0 & 0.2 \\ 1.6 & 1.6 \\ 1.7 & 1.8 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \\ 1.7 & 1.8 \end{bmatrix}$	$\begin{bmatrix} 0.0 & 0.2 \\ 1.6 & 1.6 \\ 1.7991 & 1.8 \\ 1.7937 & 1.8 \\ 0.0 & 0.0 \\ 1.7966 & 1.8 \end{bmatrix}$
clk(9,1)	$\begin{bmatrix} 1.6 & 1.6 \\ 0.0 & 0.2 \\ 0.0 & 0.1 \\ 0.0 & 0.3 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \end{bmatrix}$	$\begin{bmatrix} 1.6 & 1.6 \\ 0.0 & 0.2 \\ 0.0 & 0.0007 \\ 0.0 & 0.2599 \\ 1.7986 & 1.8 \\ 0.0 & 0.0 \end{bmatrix}$	same	same
data(9,1)	$\begin{bmatrix} 1.6 & 1.8 \\ 0.2 & 0.2 \\ 0.0 & 0.1 \\ 0.0 & 0.3 \\ 1.7 & 1.8 \\ 0.0 & 0.1 \end{bmatrix}$	$\begin{bmatrix} 1.6 & 1.8 \\ 0.2 & 0.2 \\ 0.0 & 0.0007 \\ 0.0 & 0.2599 \\ 1.7986 & 1.8 \\ 0.0 & 0.0 \end{bmatrix}$	same	same
clk(9,9)	$\begin{bmatrix} 1.6 & 1.6 \\ 1.6 & 1.8 \\ 0.0 & 0.1 \\ 1.5 & 1.8 \\ 0.0 & 0.1 \\ 1.7 & 1.8 \end{bmatrix}$	$\begin{bmatrix} 1.6 & 1.6 \\ 1.6 & 1.8 \\ 0.0 & 0.0008 \\ 1.5364 & 1.8 \\ 0.0 & 0.0006 \\ 1.7998 & 1.8 \end{bmatrix}$	same	same
data(9,9)	$\begin{bmatrix} 1.6 & 1.8 \\ 1.6 & 1.6 \\ 0.0 & 0.1 \\ 1.5 & 1.8 \\ 0.0 & 0.1 \\ 1.7 & 1.8 \end{bmatrix}$	$\begin{bmatrix} 1.6 & 1.8 \\ 1.6 & 1.6 \\ 0.0 & 0.0008 \\ 1.5364 & 1.8 \\ 0.0 & 0.0006 \\ 1.7998 & 1.8 \end{bmatrix}$	same	same

The frequency of the clock can be as high and 1.30GHz.

The maximum delay from when Φ starts to fall (1.6) to when $\bar{q}$ is stable is

$$\begin{aligned} t_{delay}^{d\uparrow} &= 84ps \\ t_{delay}^{d\downarrow} &= 123ps \end{aligned}$$

and the delay from when $\overline{\Phi}$ is high and $\bar{q}$ is stable to when q is stable is

$$\begin{aligned} t_{delay}^{\bar{q}\uparrow} &= 75ps \\ t_{delay}^{\bar{q}\downarrow} &= 115ps \end{aligned}$$

Both of them are smaller than the falling time of clock.

- MSPICE supports inputs specified by brockett annulus
- matlab version `lp_project`
- use macro model for larger circuit (inverter, etc) to speedup computation and reduce error