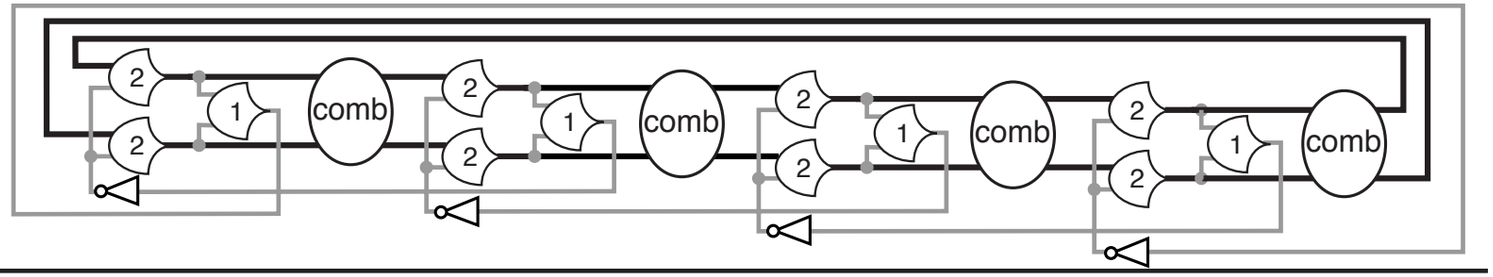
Sandbox 10

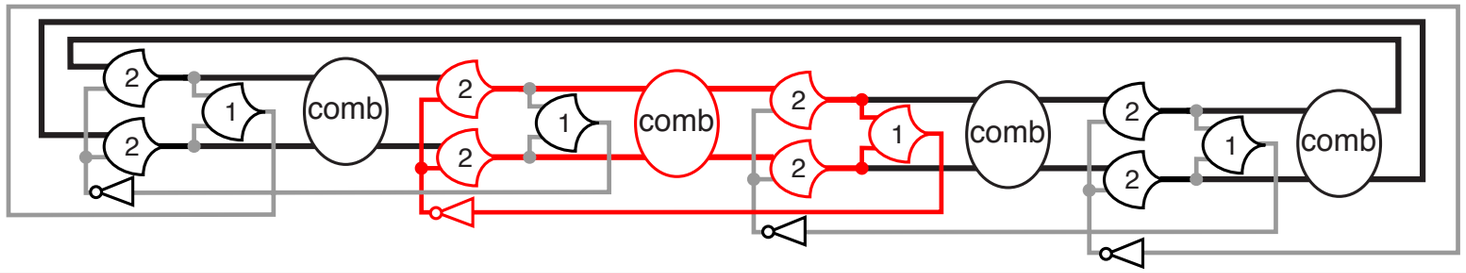
The Pipeline Ring

Ring Component Structures

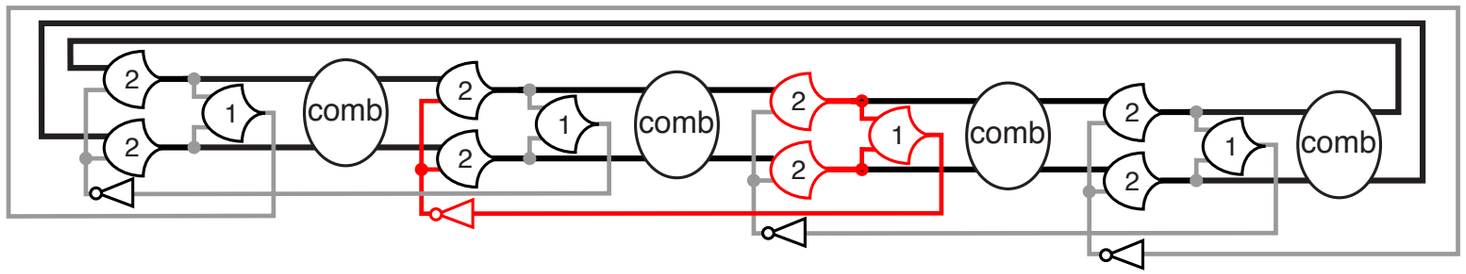
four oscillation ring



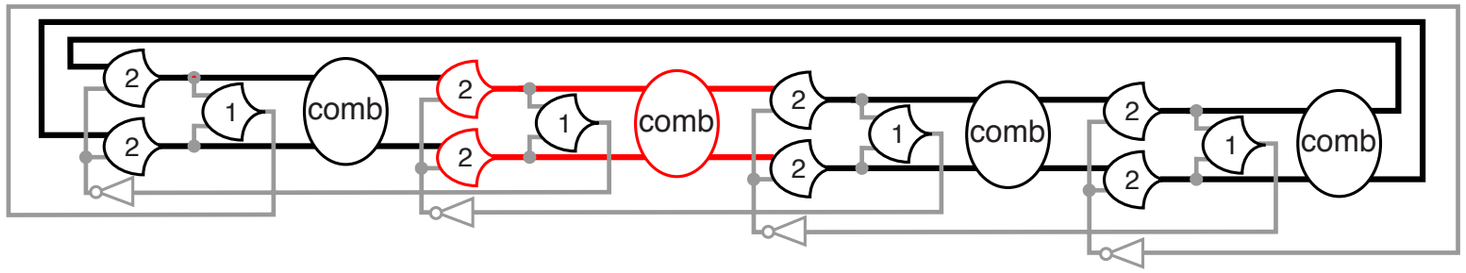
Oscillation path



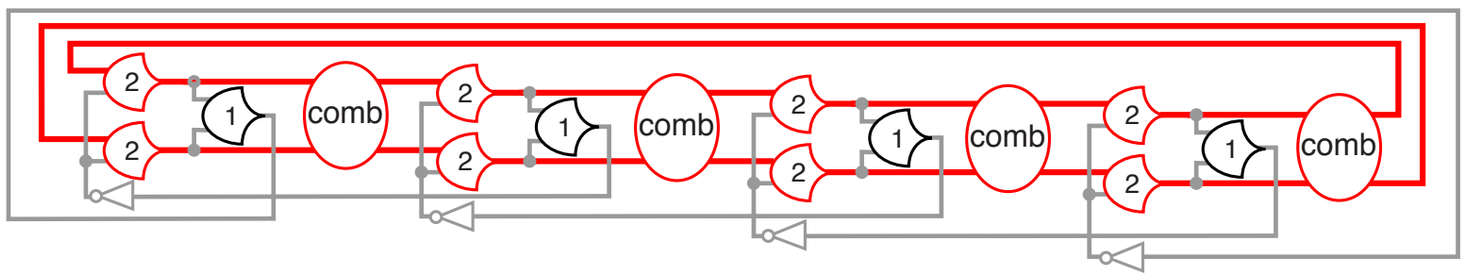
Oscillation bubble path



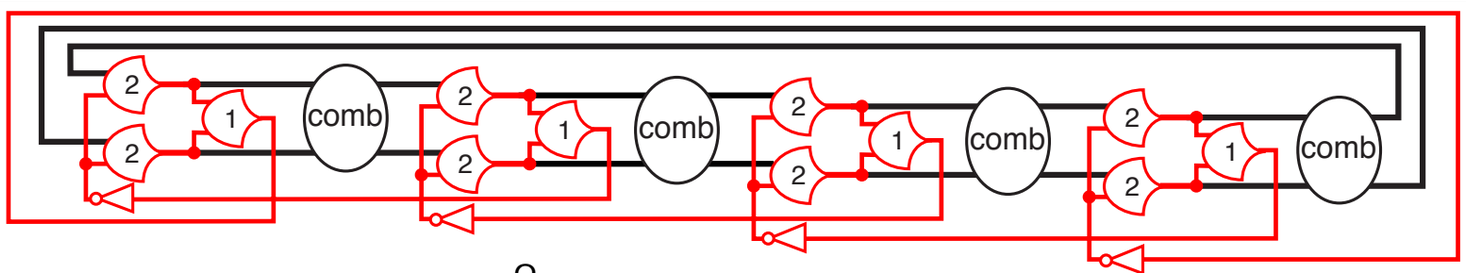
Oscillation wavefront path



Ring wavefront path
∑ oscillation wavefront paths



Ring bubble path
∑ oscillation bubble paths



Ring Behavior Referents

- slowest oscillation period (the period of the slowest oscillation in the ring),
- wavefront rejoin period (the total delay of the ring wavefront path),
- bubble rejoin period (the total delay of the ring bubble path),
- the wavefront population period (number of wavefronts times slowest oscillation period)
- the bubble population period (number of bubbles times slowest oscillation period)
- number of bubbles = number of oscillations in ring - number of wavefronts in ring
- wavefronts are always in data - empty pairs

The behavior rationale is:

Each member of a population chases its population around the ring. The critical question is whether a member ever catches up with its population and has to wait. This is determined by whether a population can propagate through the slowest oscillation (population period) before a member can propagate around the ring and overtake the population (rejoin period).

If a member does not catch up with its population it encounters no waits on its journey around the ring, therefore, its propagation time around the ring (rejoin period) is determined solely by the delays along its propagation path.

Ring Behavior Modes

Wavefront limited

If wavefront rejoin period > wavefront population period & bubble rejoin period <= bubble population period
Wavefronts free flow and do not wait on anything. Slowest oscillation and bubbles wait on wavefronts.
throughput = wavefront population/wavefront rejoin period.

Bubble limited

If bubble rejoin period > bubble population period & wavefront rejoin period <= wavefront population period
Bubbles free flow and do not wait on anything. Slowest oscillation and wavefronts wait on bubbles .
throughput = bubble population/bubble rejoin period.

Delay limited

If both rejoin periods are < their respective population periods
The slowest oscillation does not wait on anything. Wavefronts and bubbles wait on the slowest oscillation.
throughput = period of slowest oscillation.

Perfect balance

Rejoin periods and population periods are all equal
Nobody waits. Wavefronts, bubbles flow around the ring with perfect just in time arrival.
throughput = wavefront population/wavefront rejoin period.

Deadlock

number of bubbles = 0

Ring Behavior Tables

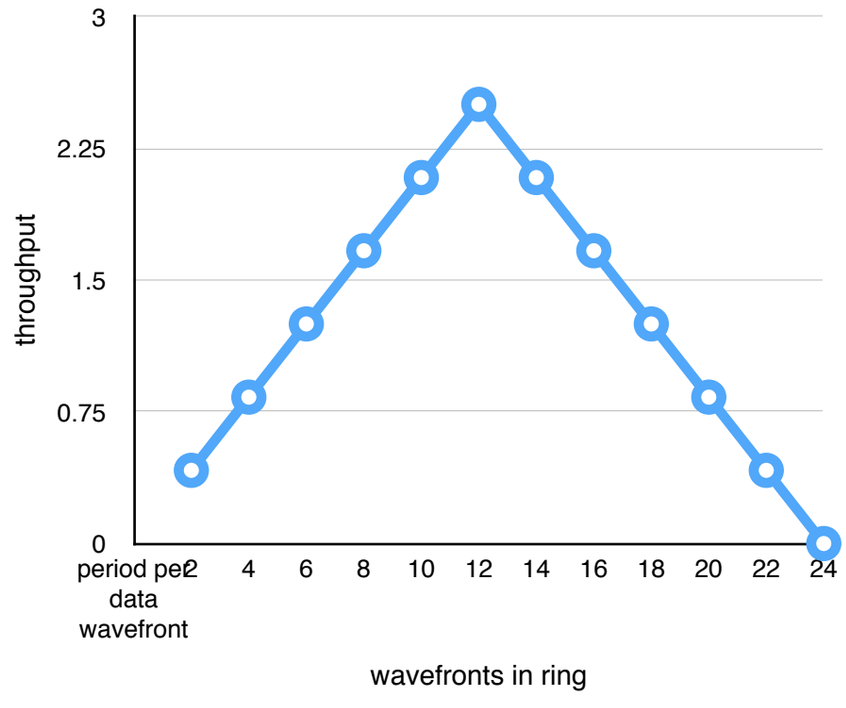
The spreadsheet tables model ring behavior in terms of the quantities defined above

balanced corresponds to ring24bal.v														
Forward wavefront buf	fun	Reverse bubble buf	fun	oscillation period buf	fun	osc in ring	waves in ring	bubbles in ring	wave population period	bubble population period	wave rejoin period	bubble rejoin period	period per data wavefront	data throughput gHz	
100	100	100	100	200	200	24	2	22	400	4400	2400	2400	2400.00	0.42	wave limited
100	100	100	100	200	200	24	4	20	800	4000	2400	2400	1200.00	0.83	wave limited
100	100	100	100	200	200	24	6	18	1200	3600	2400	2400	800.00	1.25	wave limited
100	100	100	100	200	200	24	8	16	1600	3200	2400	2400	600.00	1.67	wave limited
100	100	100	100	200	200	24	10	14	2000	2800	2400	2400	480.00	2.08	wave limited
100	100	100	100	200	200	24	12	12	2400	2400	2400	2400	400.00	2.50	perfect balance
100	100	100	100	200	200	24	14	10	2800	2000	2400	2400	480.00	2.08	bubble limited
100	100	100	100	200	200	24	16	8	3200	1600	2400	2400	600.00	1.67	bubble limited
100	100	100	100	200	200	24	18	6	3600	1200	2400	2400	800.00	1.25	bubble limited
100	100	100	100	200	200	24	20	4	4000	800	2400	2400	1200.00	0.83	bubble limited
100	100	100	100	200	200	24	22	2	4400	400	2400	2400	2400.00	0.42	bubble limited
100	100	100	100	200	200	24	24	0	4800	0	2400	2400	0.00	0.00	deadlock
		slowest cycle			200										

Ring behavior is quantized

Ring behavior occurs in discrete steps. A pipeline ring is a closed structure composed of elements that only occur as whole quantities. There cannot be a partial oscillation or a partial wavefront. On the ring behavior graphs there are lines connecting the behavior points to show relationships but there is no behavior on the lines between the points. There is only ring behavior at the points.

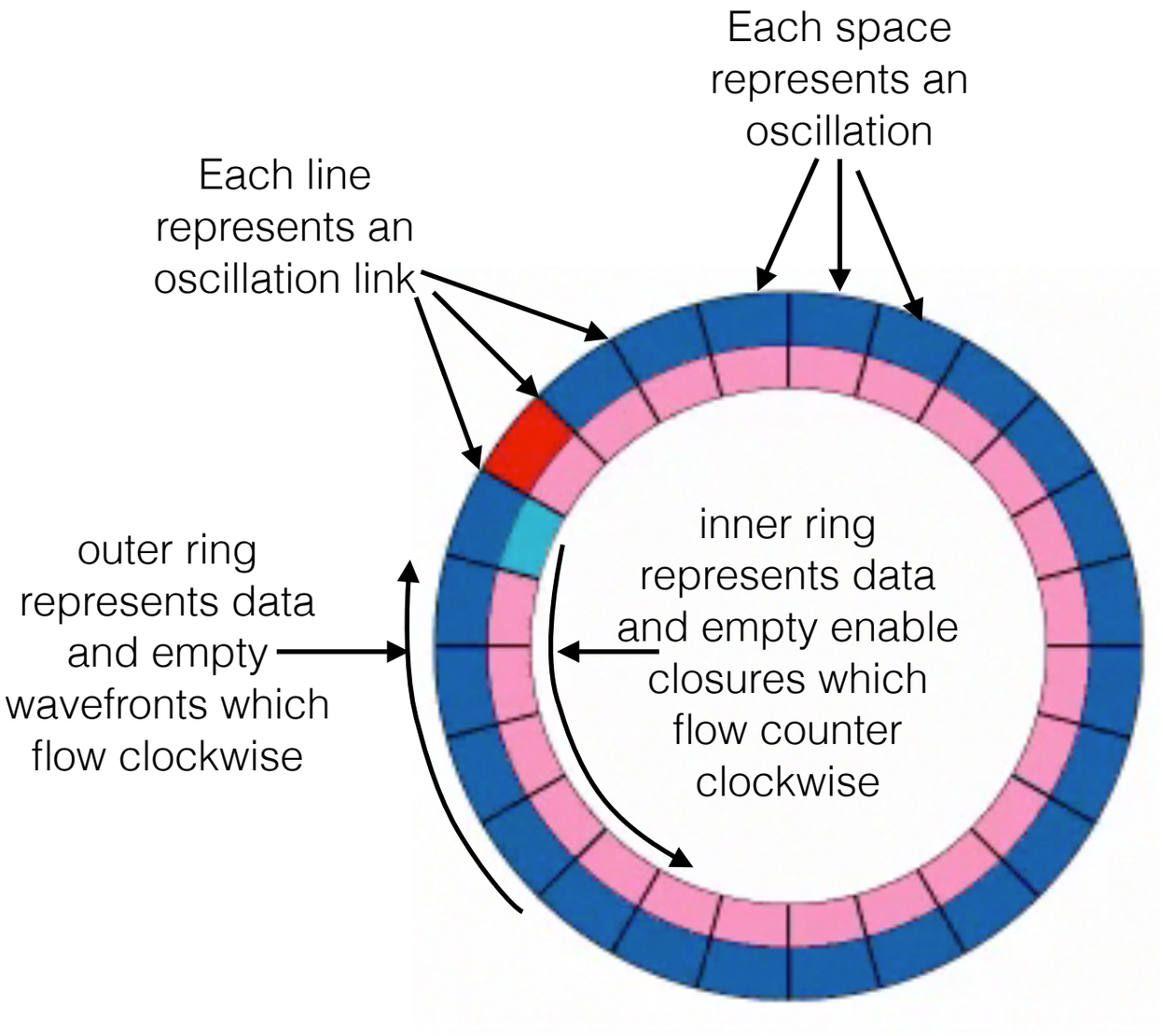
The shape of the curve can change with varying delays but for a 24 oscillation ring there is always exactly 11 non deadlock behavior points defining the curve.

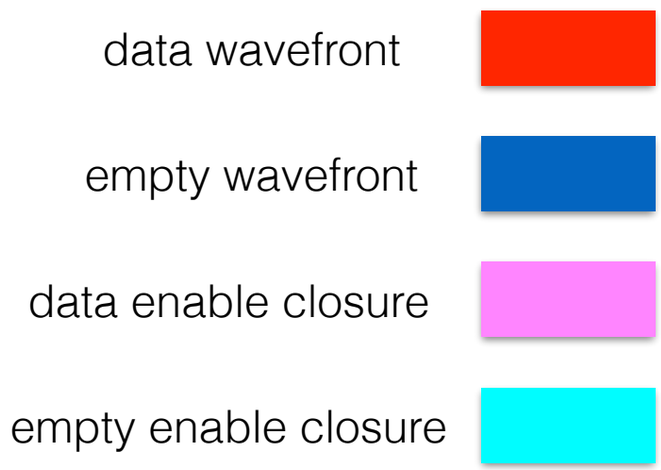


Ring Movies

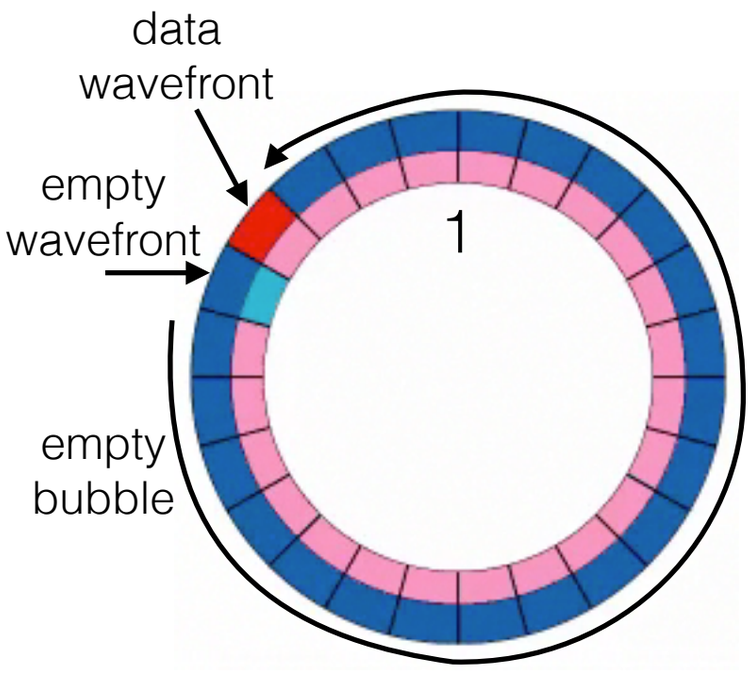
The ring movies present a God's eye view of ring behavior.

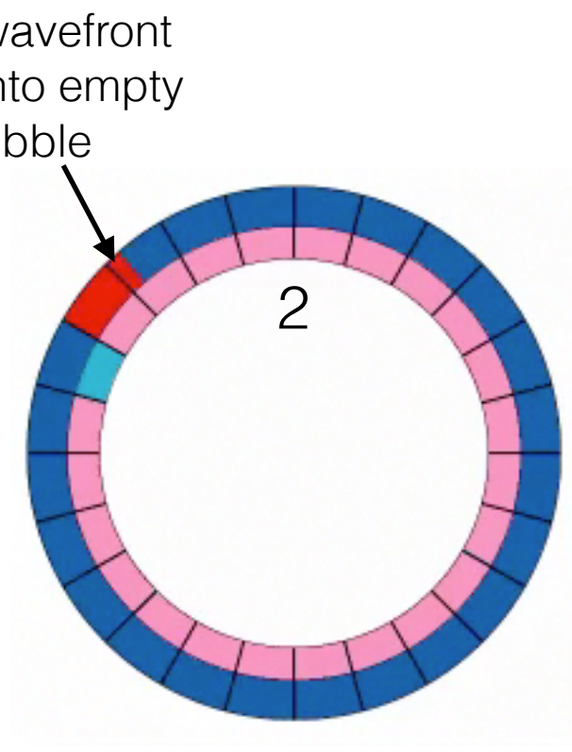
Ring Movie Basics

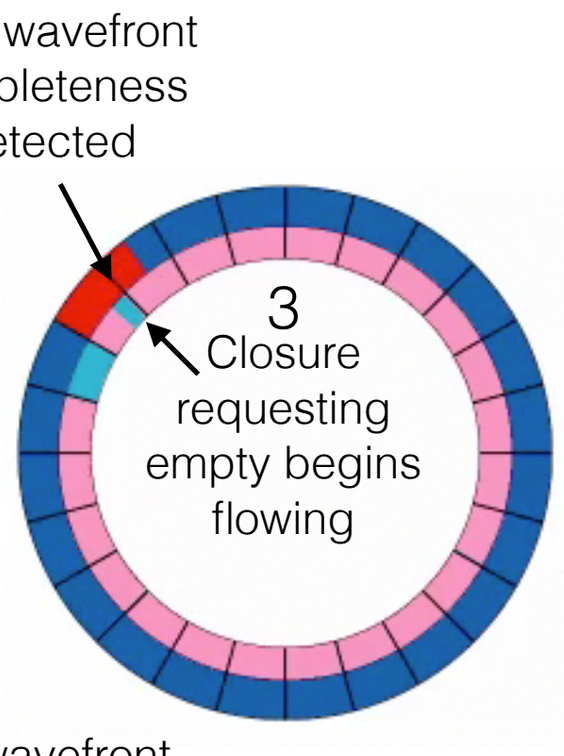


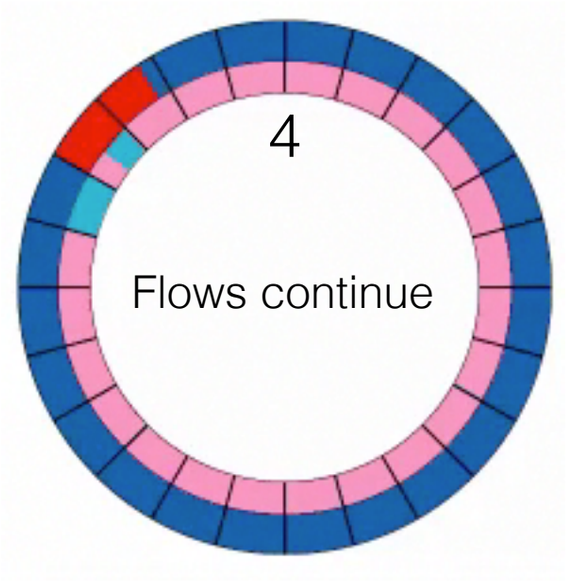


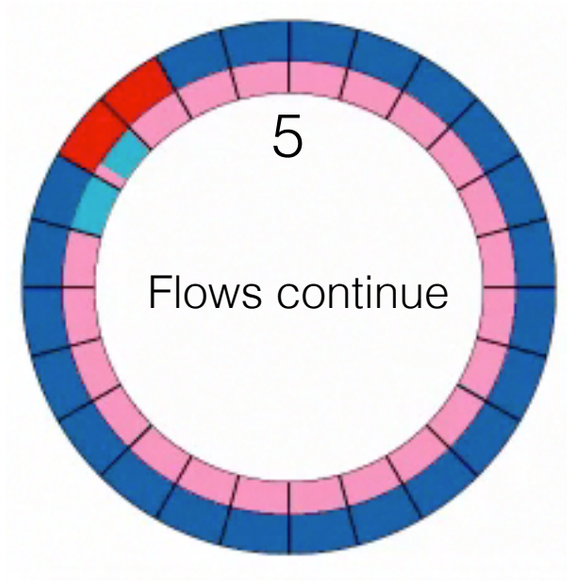
Ring Movie Dynamics 1

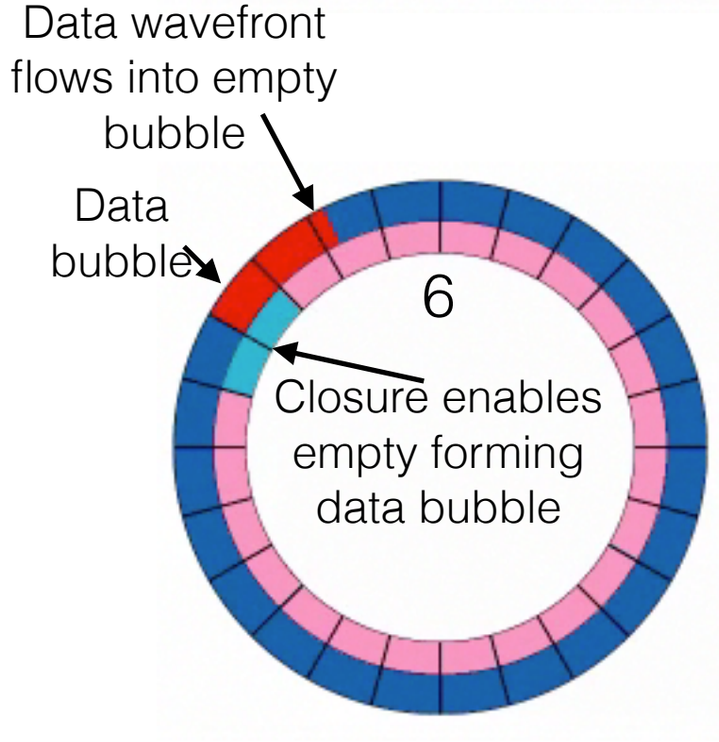




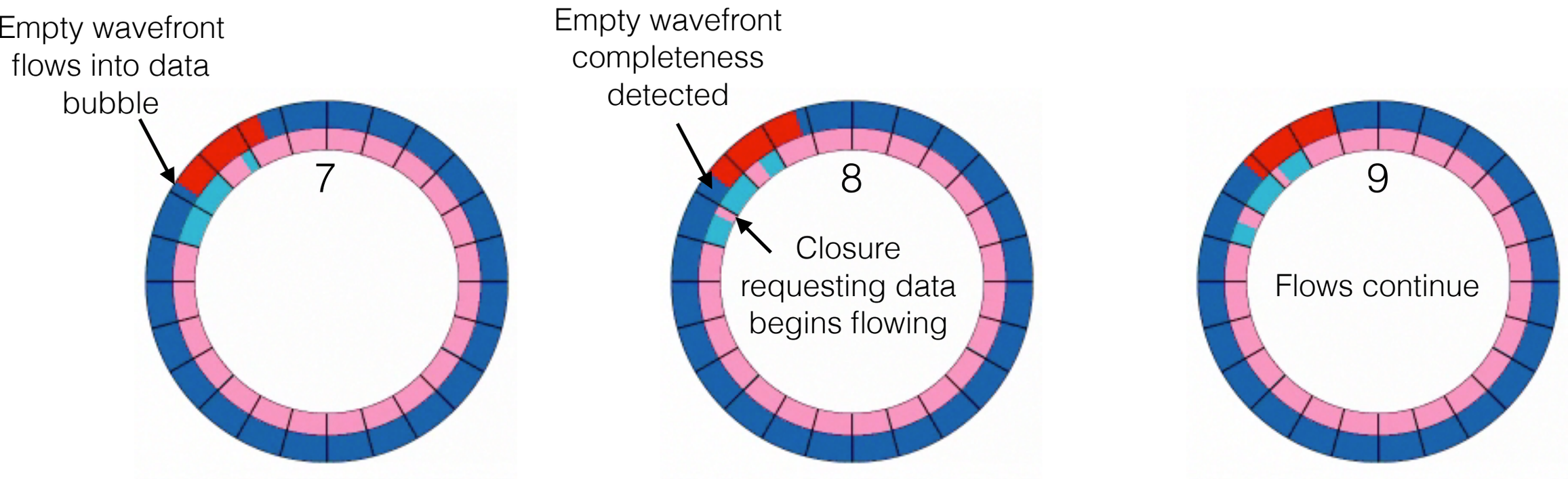








Ring Movie Dynamics 2

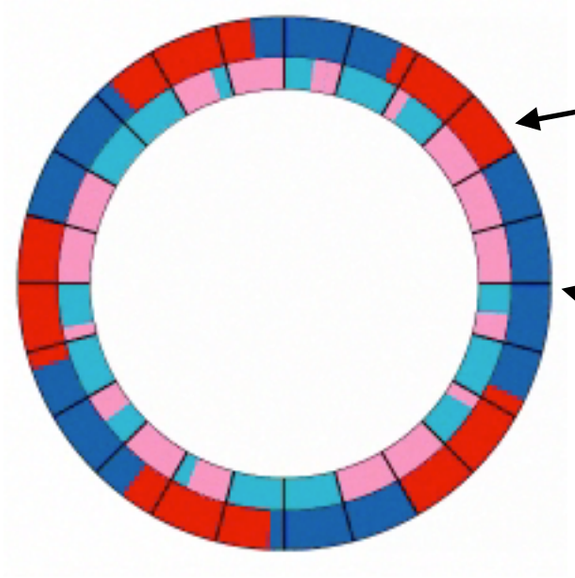


Wavefront Limited Behavior

There are sufficient bubbles for all wavefronts to flow freely. Bubbles wait on wavefronts.
(wavefront rejoin period > wavefront population period & bubble rejoin period < bubble population period)

movie
10 wavefronts.mov

10 wavefronts
14 bubbles

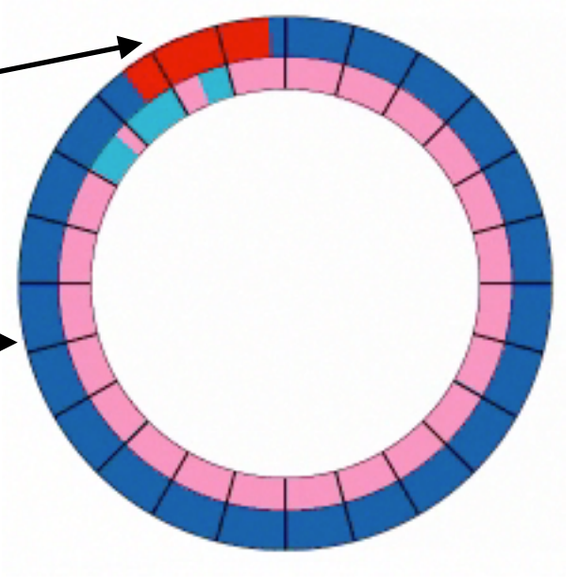


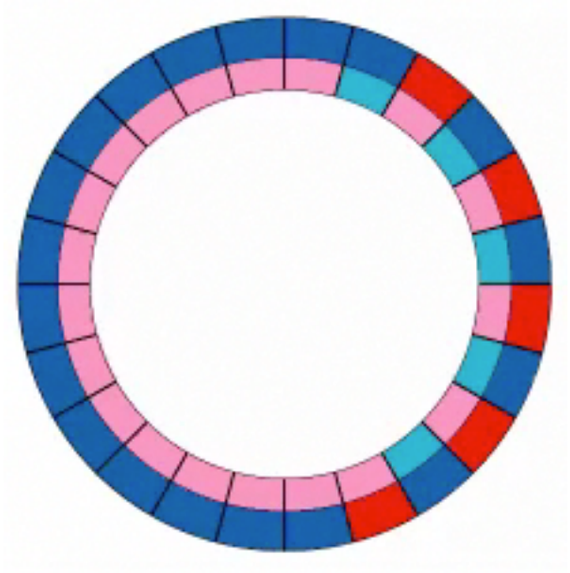
Wavefronts free flow and never wait

Bubbles jam up waiting for wavefronts

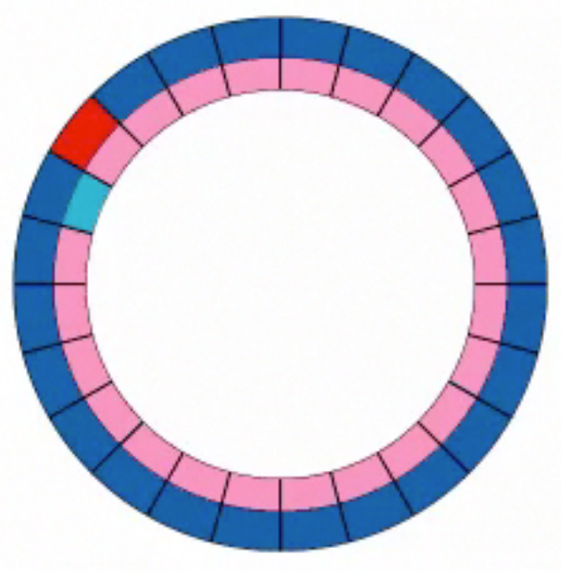
movie
2 wavefronts.mov

2 wavefronts
22 bubbles





Throughput of the ring is how many wavefronts are in the ring and how long it takes a wavefront to flow around the ring. (number of wavefronts/wavefront rejoin period)

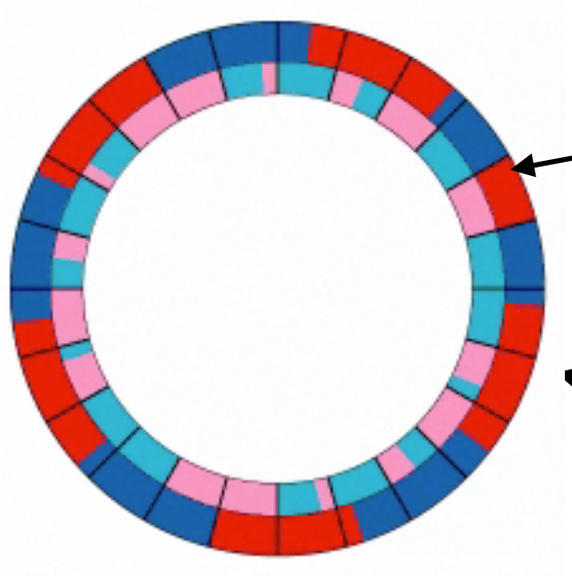


Bubble Limited Behavior

There are sufficient wavefronts for all bubbles to flow freely. wavefronts wait on bubbles.
(bubble rejoin period > bubble population period & wavefront rejoin period < wavefront population period)

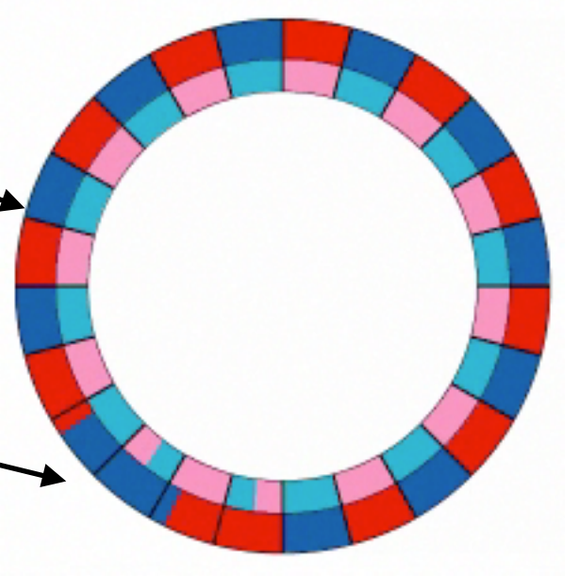
movie
12 wavefronts.mov

12 wavefronts
12 bubbles



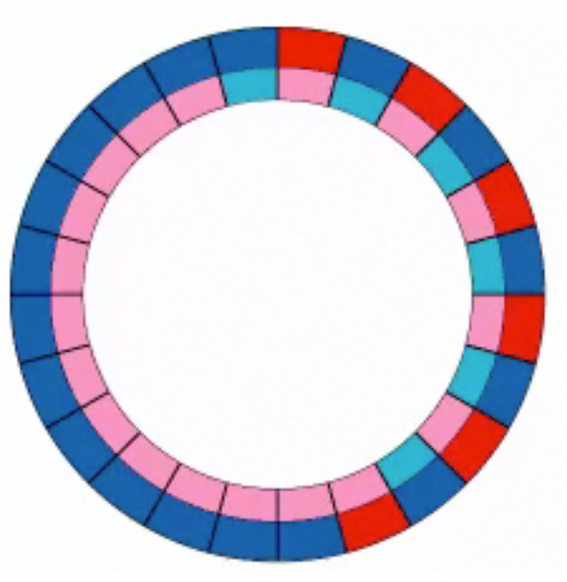
Wavefronts jam up waiting for bubbles

Bubbles free flow and never wait

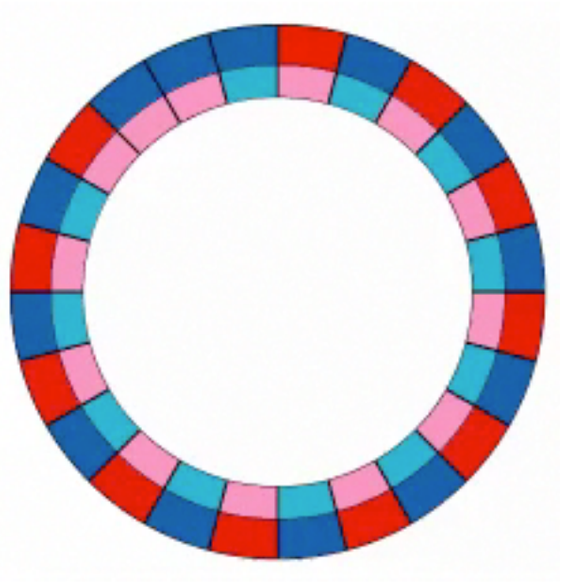


movie
22 wavefronts.mov

22 wavefronts
2 bubbles

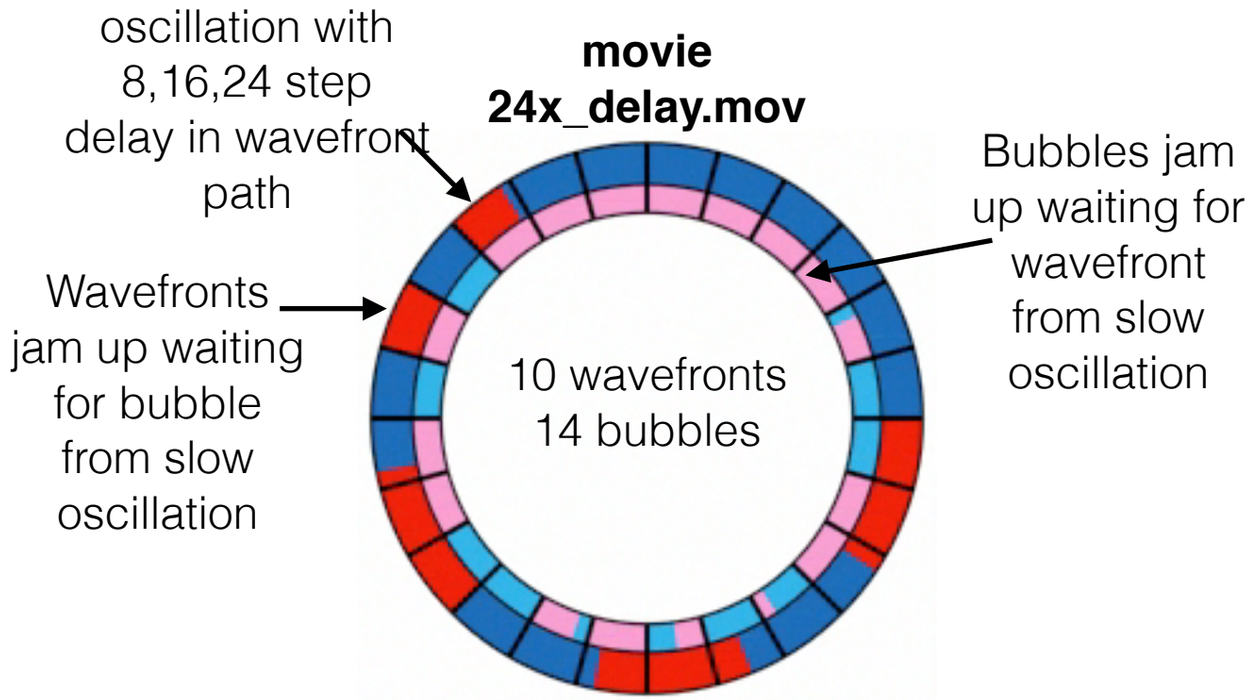


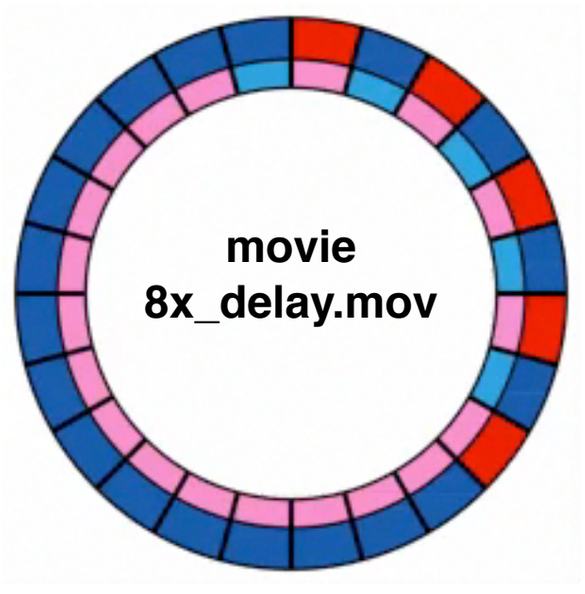
Throughput of the ring is how many bubbles are in the ring and how long it takes a bubbles to flow around the ring.
(number of bubbles/bubble rejoin period)

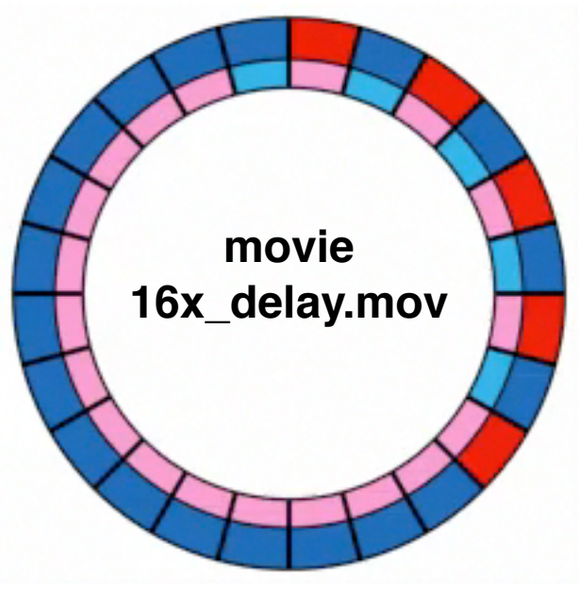


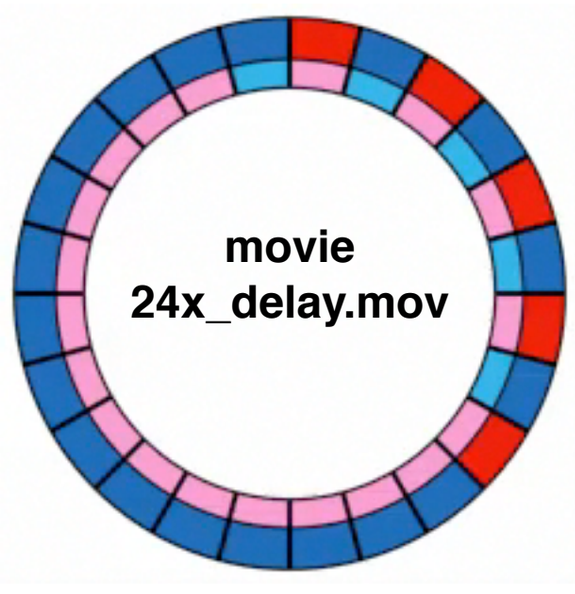
Delay Limited Behavior

Wavefronts and bubbles wait on the slow oscillation.
(bubble rejoin period < bubble population period & wavefront rejoin period < wavefront population period)





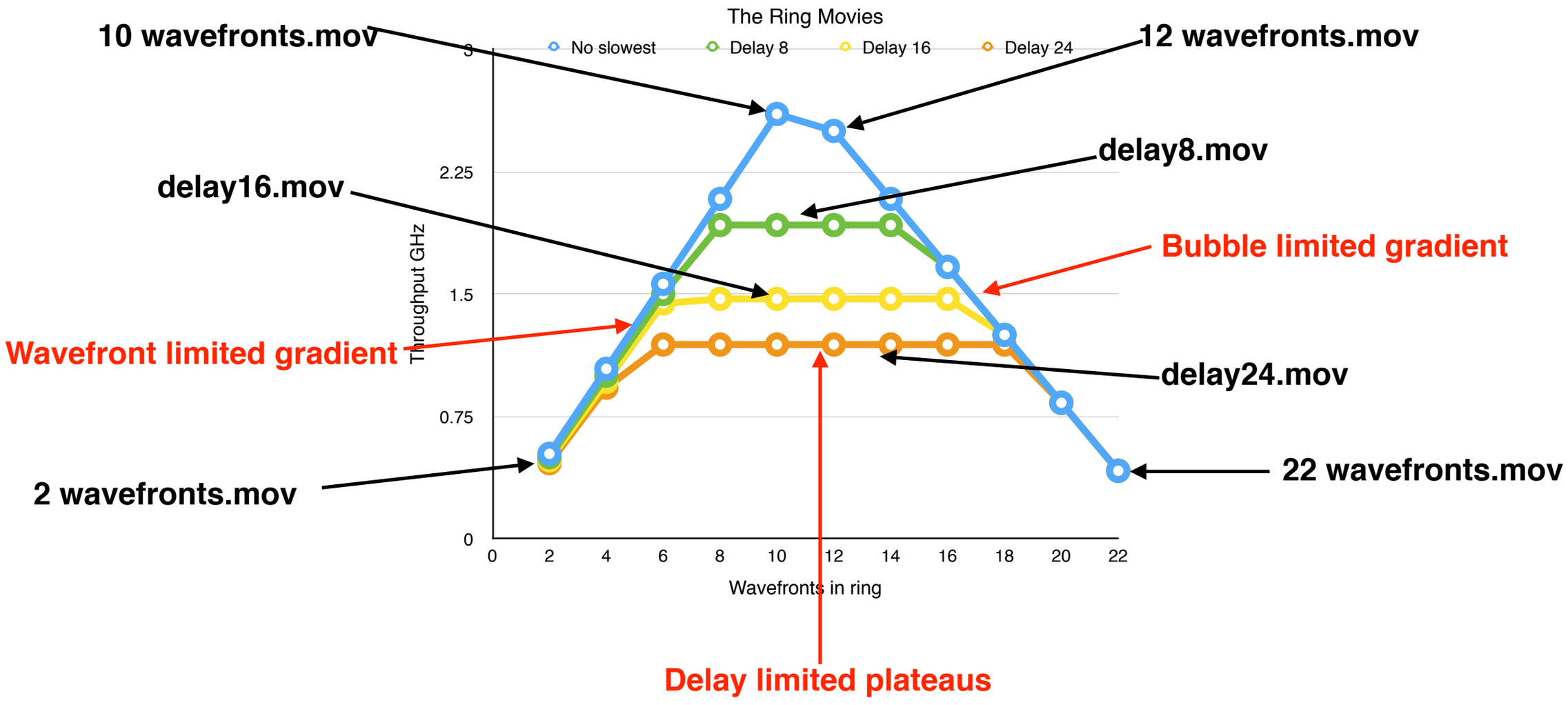




Throughput of the ring is the period of the slowest oscillation.
(slowest oscillation period)

Ring Movie Behavior Profiles

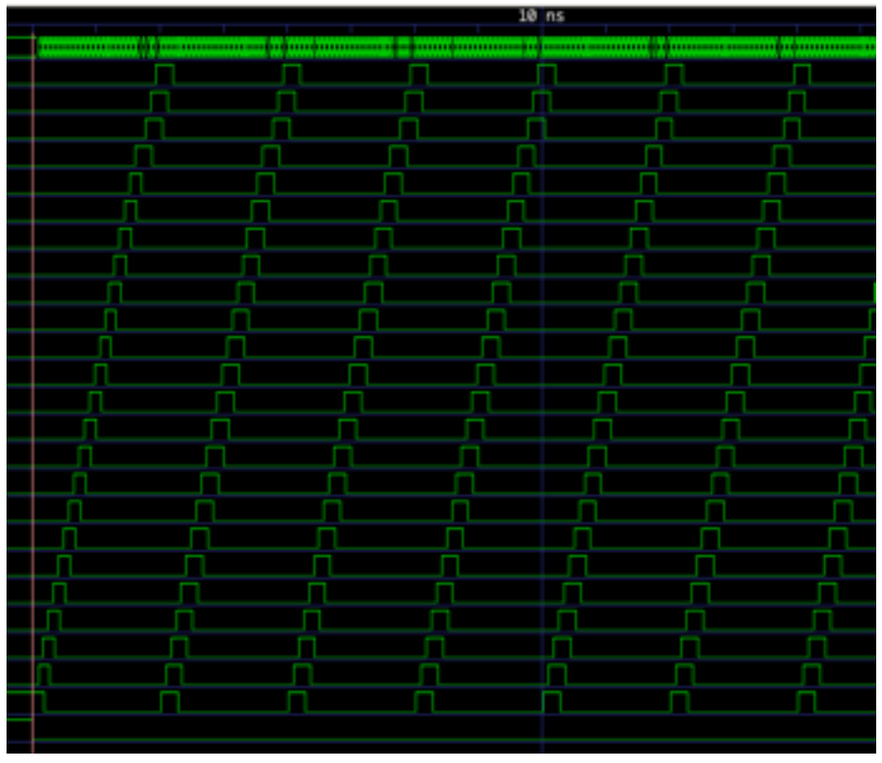
From ring movies spread sheet which is set up to match the delay ratios of the ring movies.



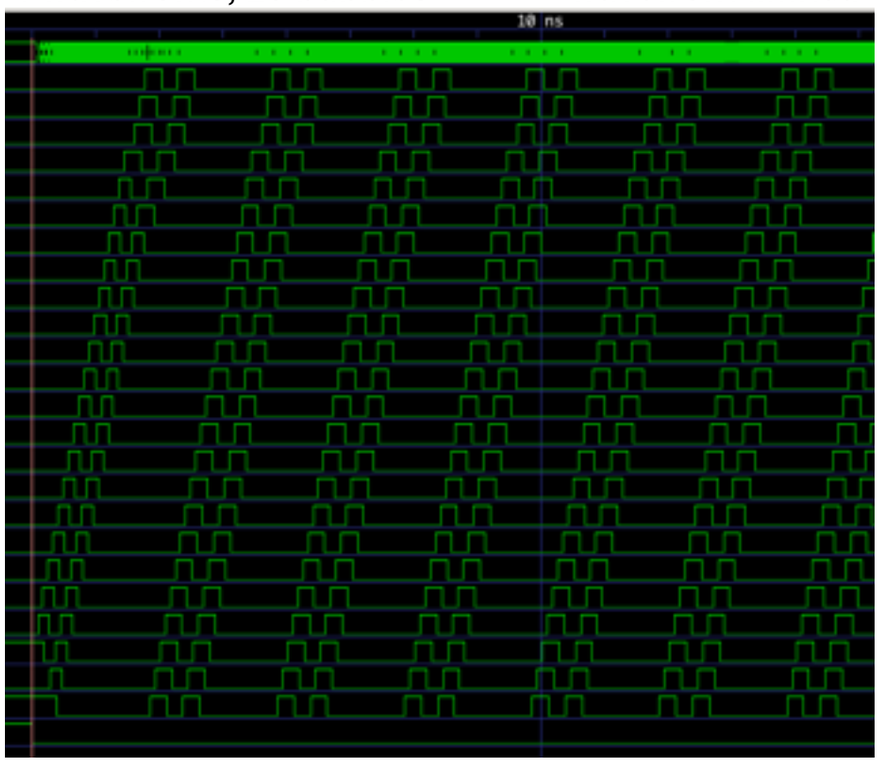
delay 8.mov

Simulation matches wavefront and bubble delay ratios of movies

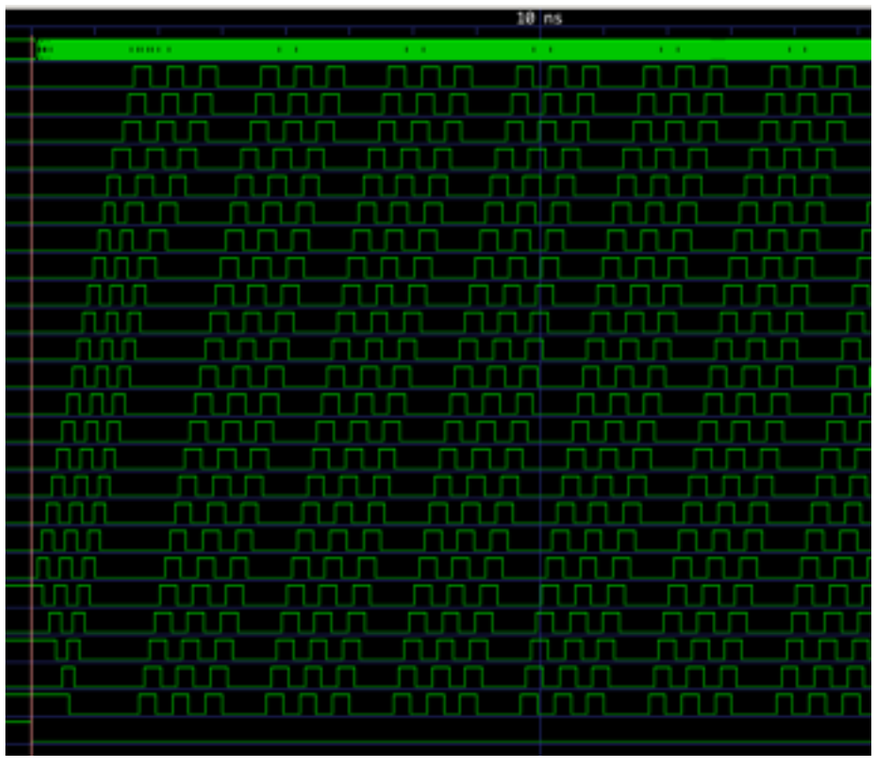
2 wavefronts, 22 bubbles **wavefront limited**



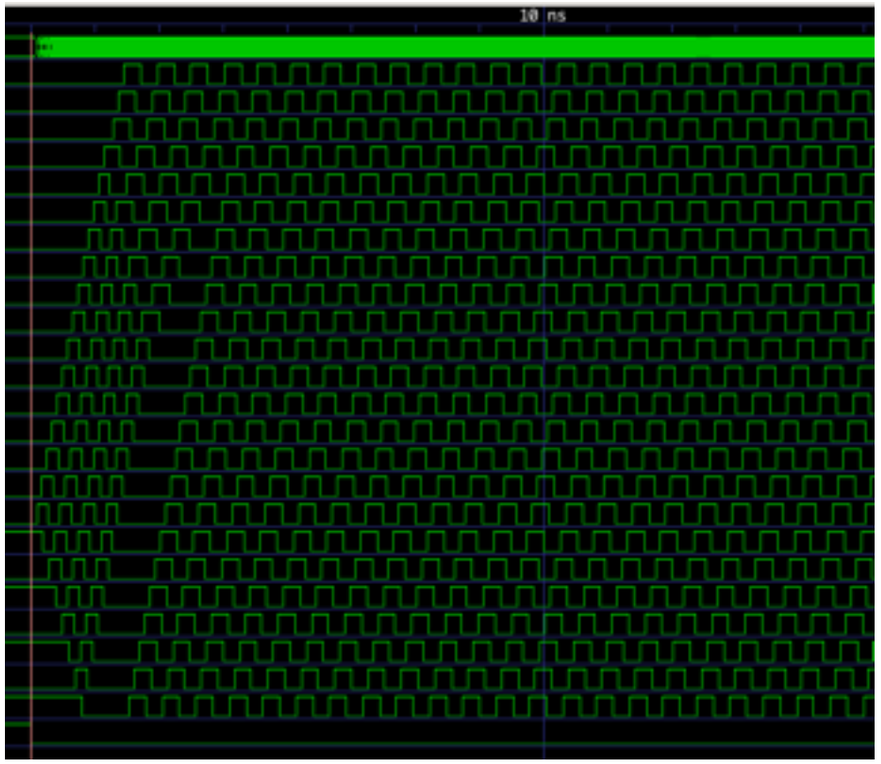
4 wavefronts, 20 bubbles **wavefront limited**



6 wavefronts, 18 bubbles **wavefront limited**



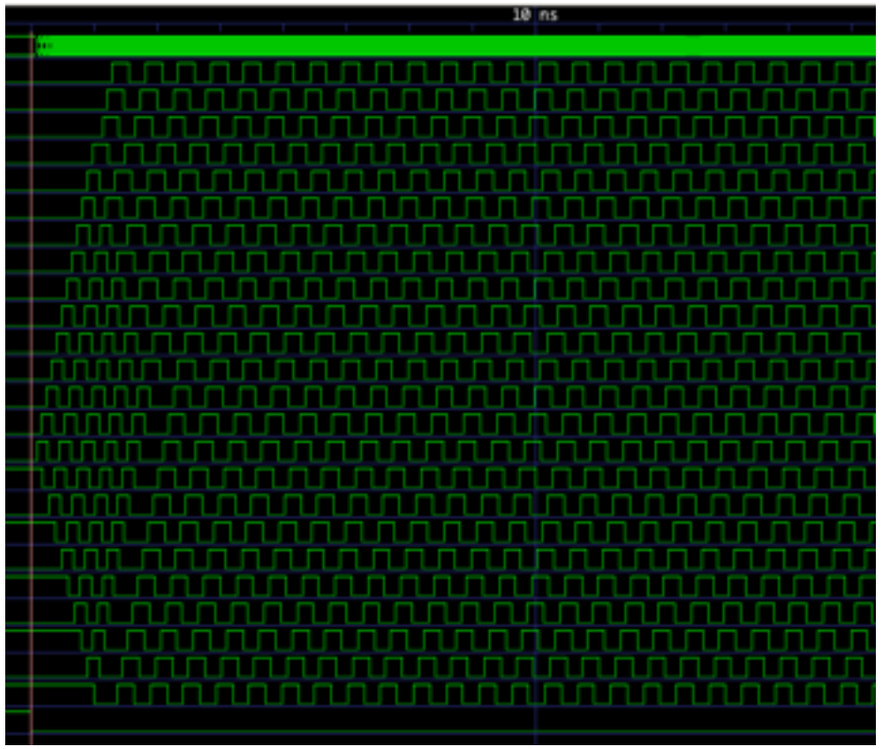
8 wavefronts, 16 bubbles **delay limited**



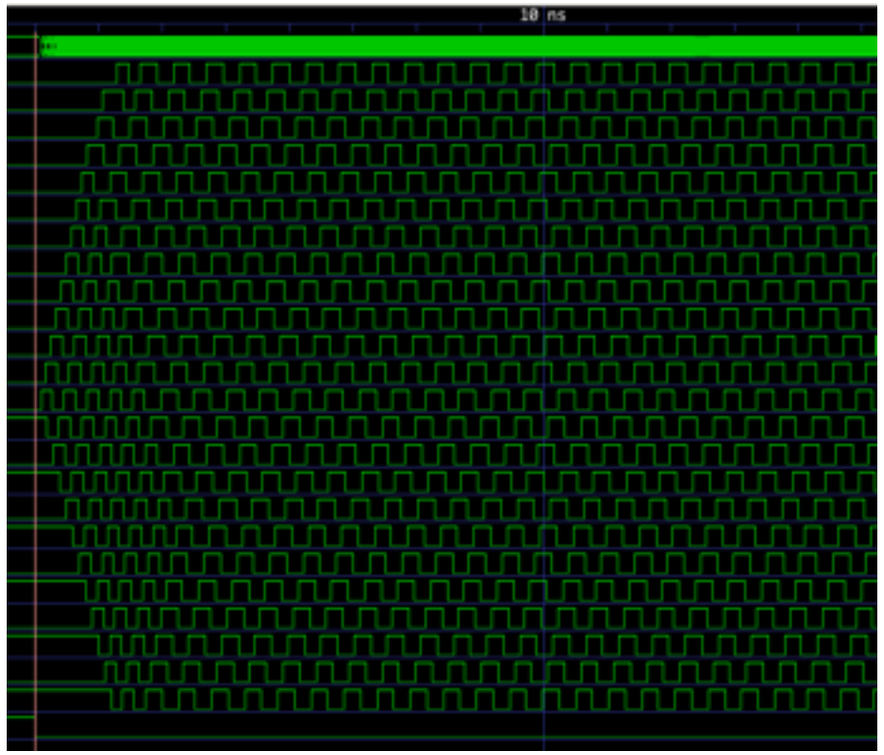
delay 8.mov

Simulation matches wavefront and bubble delay ratios of movies

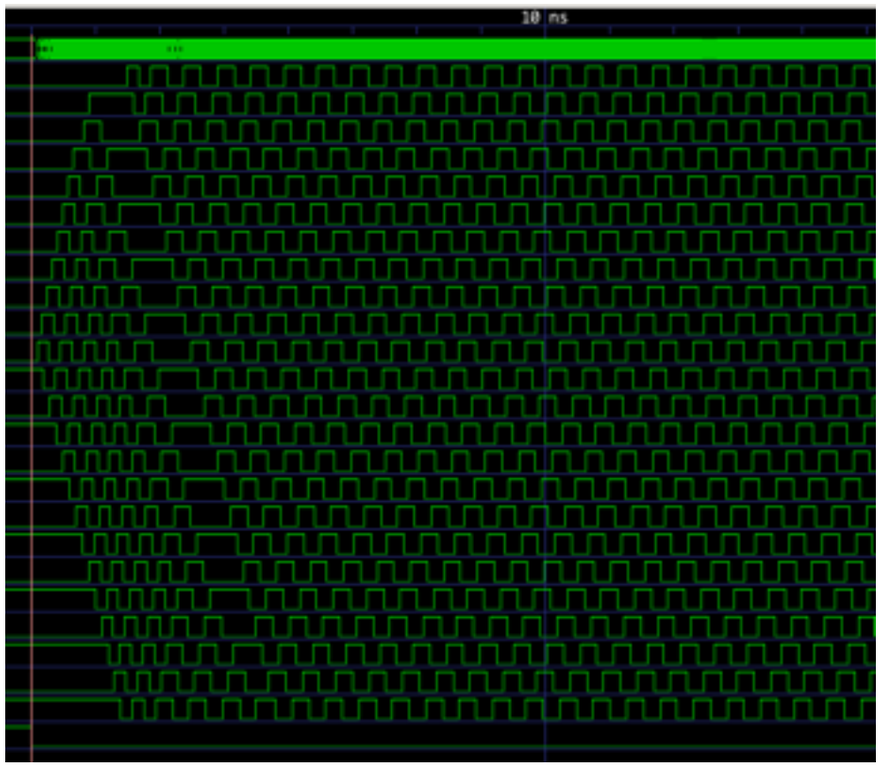
10 wavefronts, 14 bubbles **delay limited**



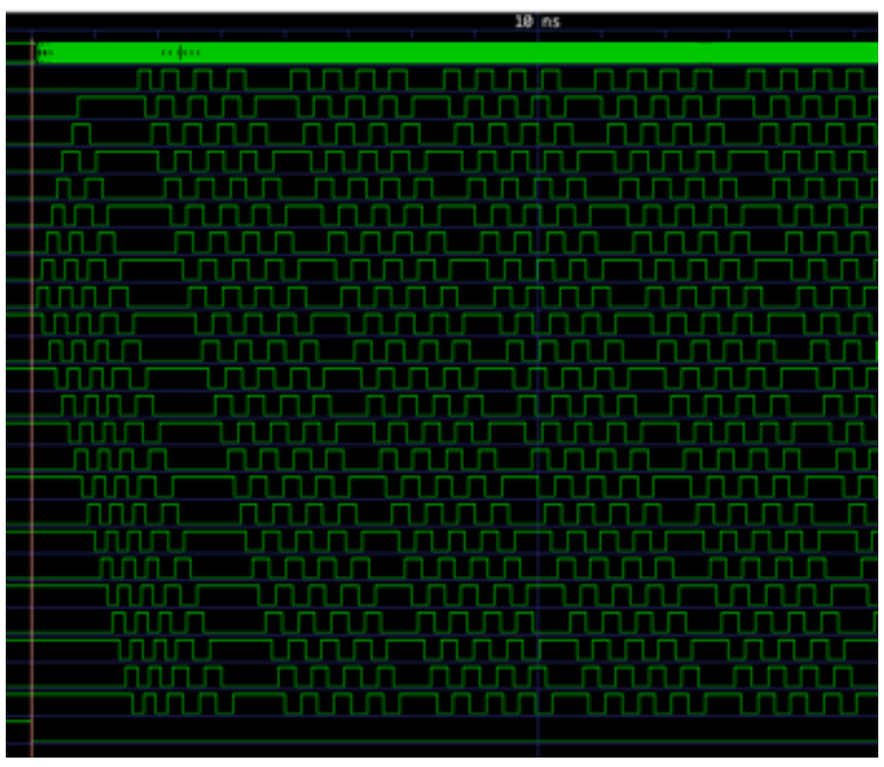
12 wavefronts, 12 bubbles **delay limited**



14 wavefronts, 10 bubbles **delay limited**

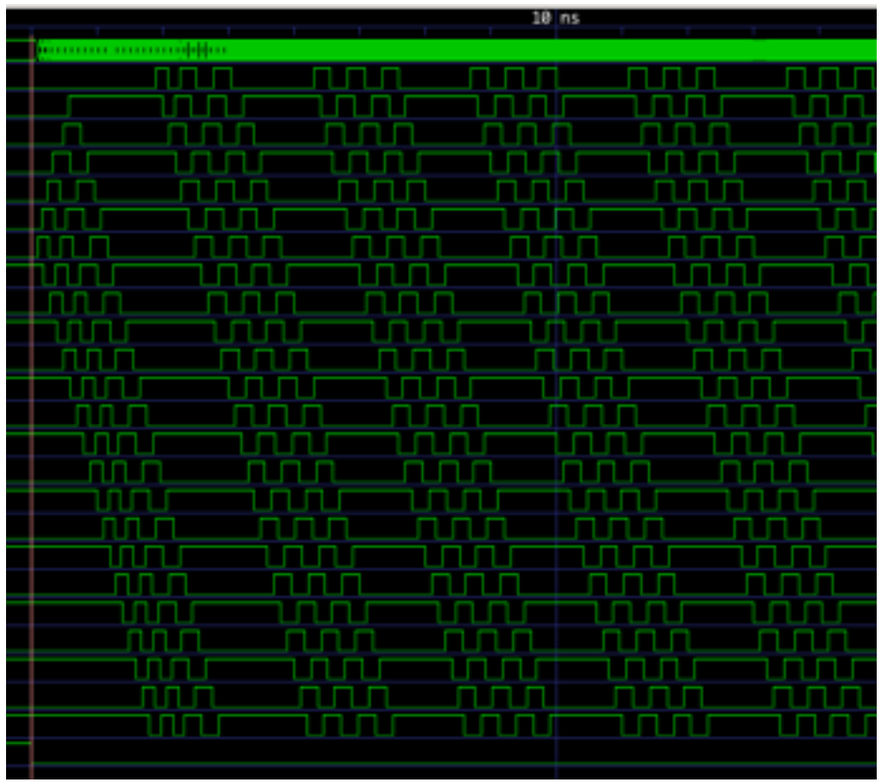


16 wavefronts, 8 bubbles **bubble limited**

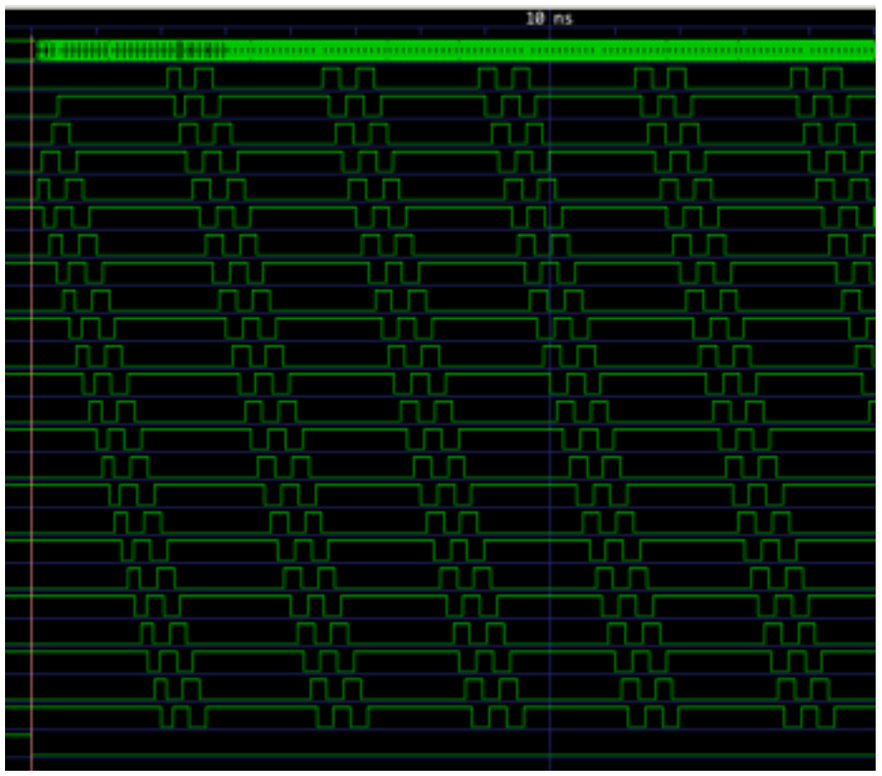


delay 8.mov Simulation matches wavefront and bubble delay ratios of movies

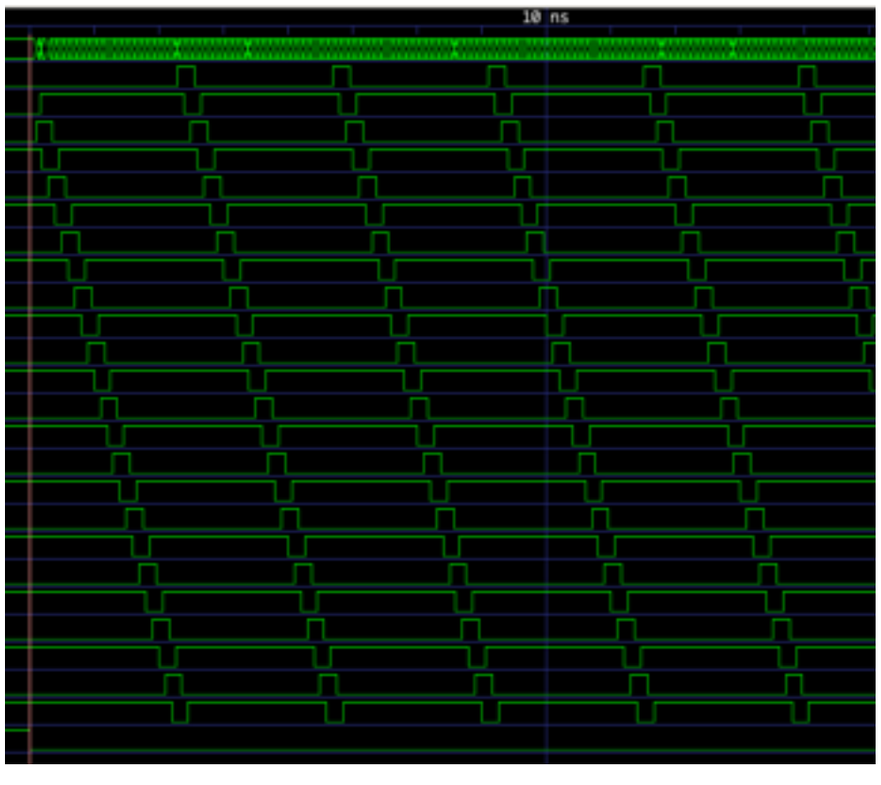
18 wavefronts, 6 bubbles **bubble limited**



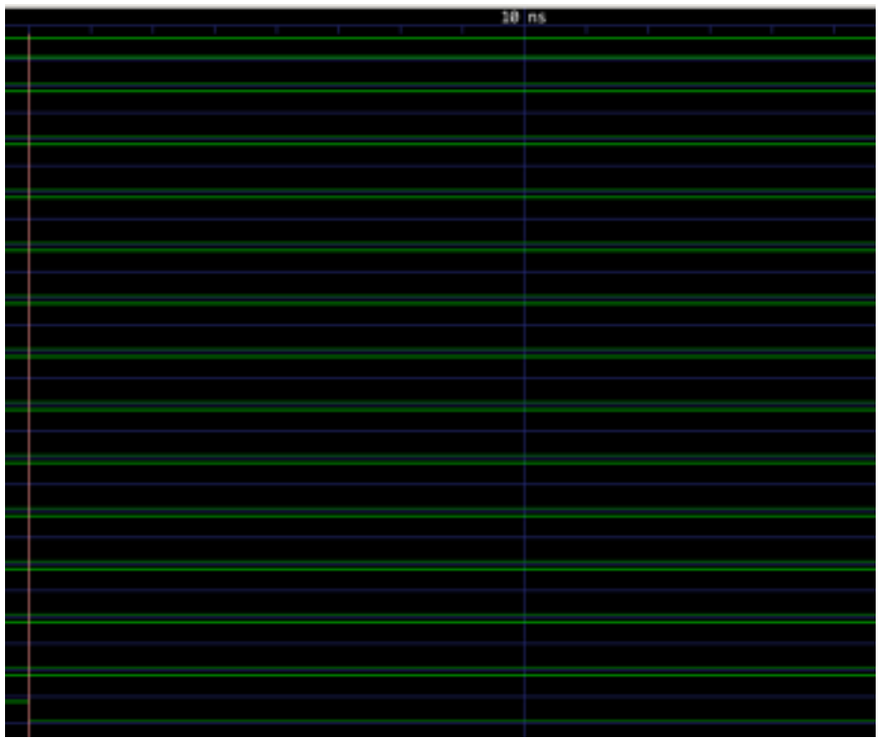
20 wavefronts, 4 bubbles **bubble limited**



22 wavefronts, 2 bubbles **bubble limited**

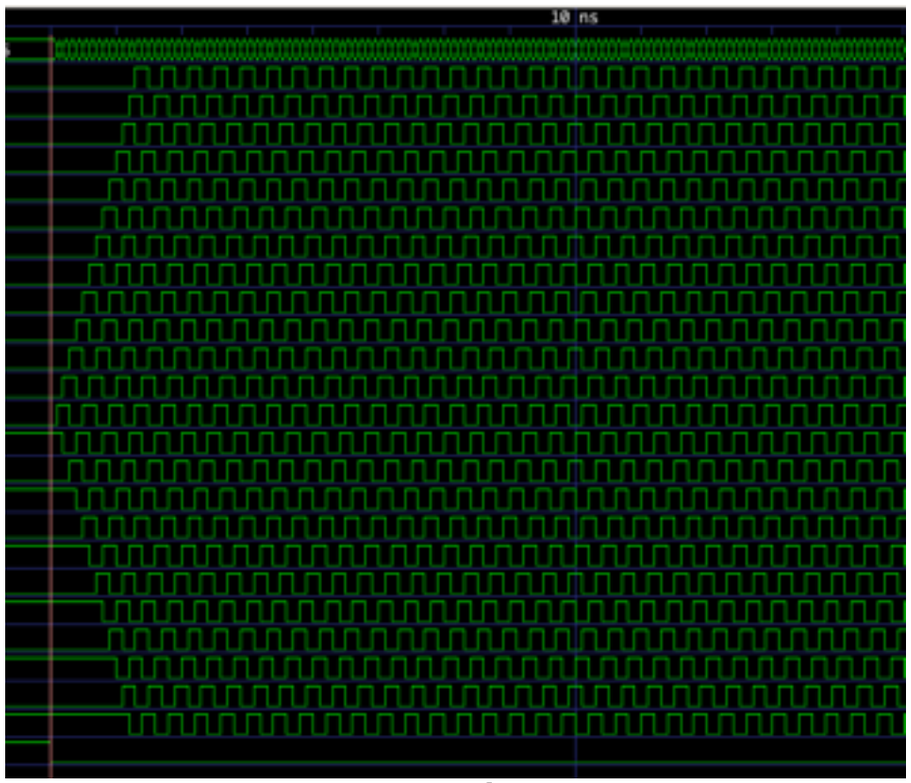


24 wavefronts, 0 bubbles **deadlocked**

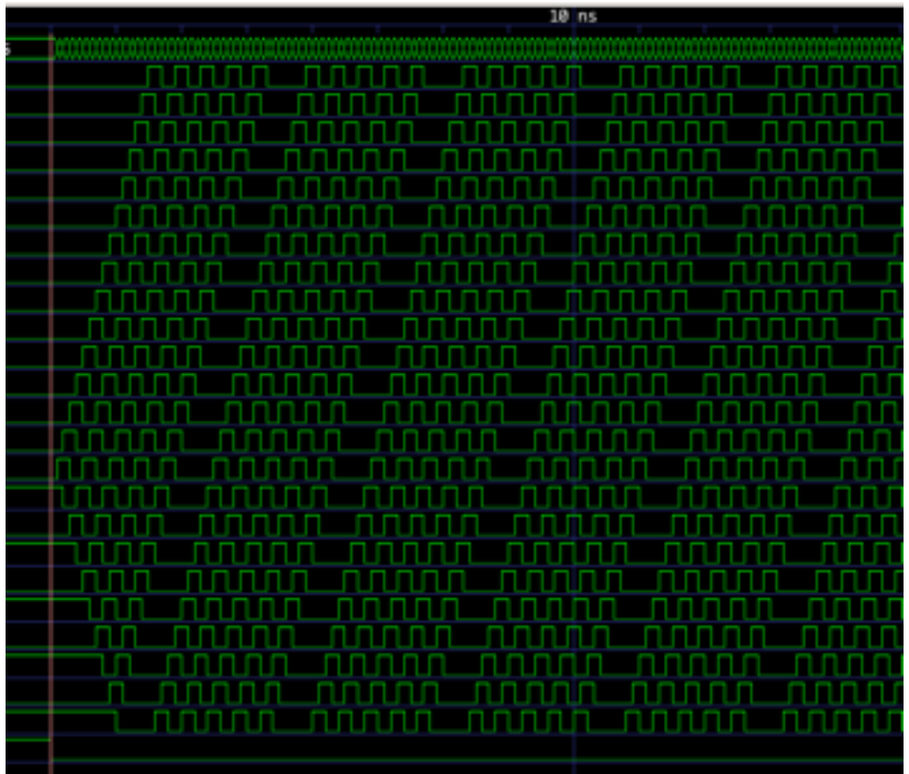


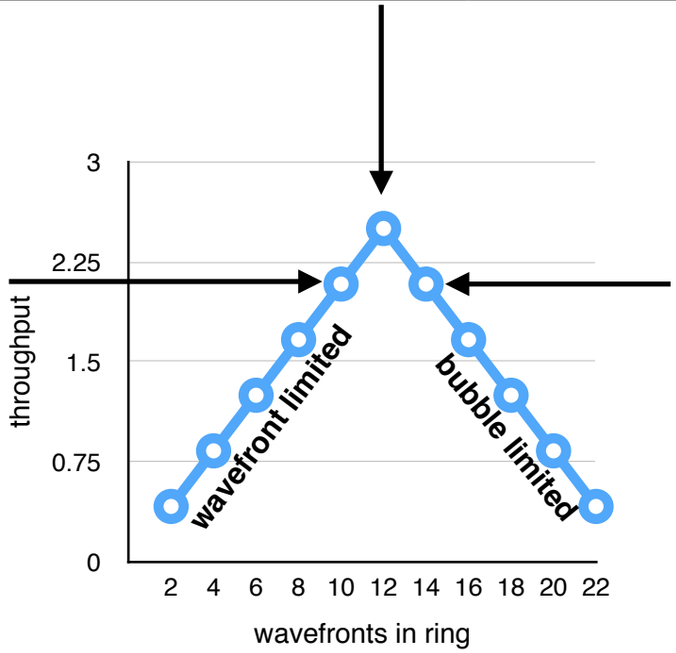
The Perfectly Balanced Ring - ring24bal.v

12 wavefronts, 12 bubbles **perfect balance**



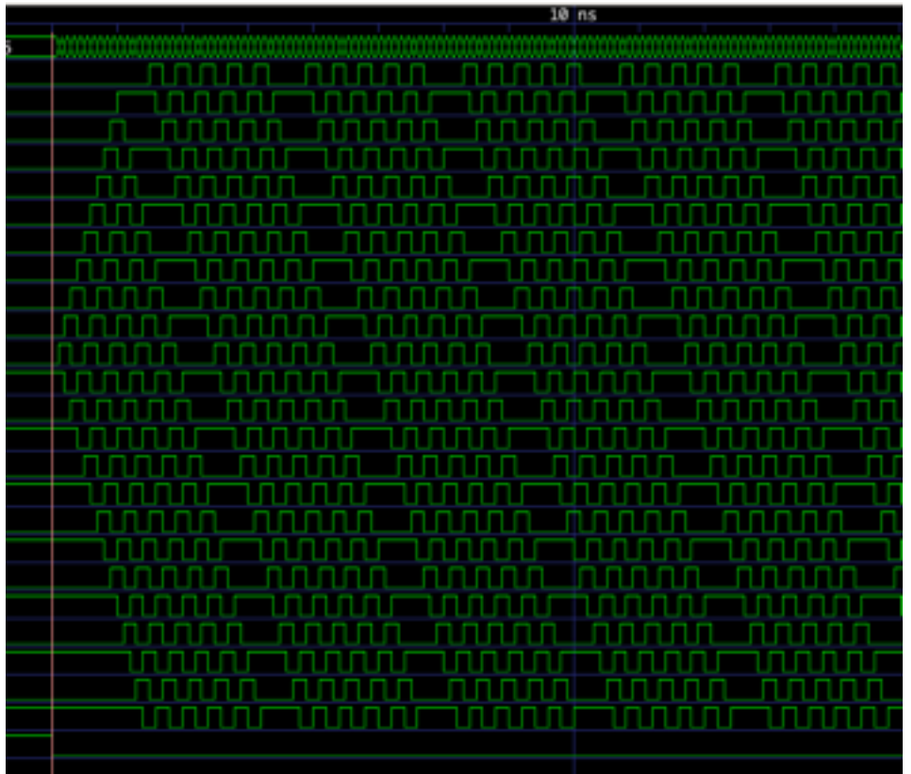
10 wavefronts, 14 bubbles **wavefront limited**





from balanced ring spreadsheet table

14 wavefronts, 10 bubbles **bubble limited**



Three and Four Oscillation Rings

The most common examples of ring are three and four oscillation rings

A ring must contain at least three oscillations.
There are at least two wavefronts, one data and one empty and there must be at least one bubble. Unless one oscillation is very slow a three oscillation ring will be bubble limited.

Optimal throughput typically occurs when each wavefront has a bubble to flow into, so a perfectly balanced four oscillation ring will provide optimal throughput.

The spreadsheet tables completely characterize three and four oscillation rings to facilitate their study and comparison.

Four oscillation ring																				
Forward wavefront path				Reverse bubble/closure path				oscillation period				osc in ring	waves in ring	bubbles in ring	wave population period	wave rejoin period	bubble population period	bubble rejoin period	period per data wavefront	data throughput gHz	
osc A	osc B	osc C	osc D	osc A	osc B	osc C	osc D	osc A	osc B	osc C	osc D										
50	60	60	60	60	60	60	60	110	120	120	120	4	2	2	240	230	240	240	240.00	4.17	delay limited
70	60	60	60	60	60	60	60	130	120	120	120	4	2	2	260	250	260	240	260.00	3.85	delay limited
90	60	60	60	60	60	60	60	150	120	120	120	4	2	2	300	270	300	240	300.00	3.33	delay limited
110	60	60	60	60	60	60	60	170	120	120	120	4	2	2	340	290	340	240	340.00	2.94	delay limited
130	60	60	60	60	60	60	60	190	120	120	120	4	2	2	380	310	380	240	380.00	2.63	delay limited
150	60	60	60	60	60	60	60	210	120	120	120	4	2	2	420	330	420	240	420.00	2.38	delay limited
170	60	60	60	60	60	60	60	230	120	120	120	4	2	2	460	350	460	240	460.00	2.17	delay limited
190	60	60	60	60	60	60	60	250	120	120	120	4	2	2	500	370	500	240	500.00	2.00	delay limited
Three oscillation ring																					
50	60	60	xxx	60	60	60	xxx	110	120	120	xxx	3	2	1	240	170	120	180	360.00	2.78	bubble limited
70	60	60	xxx	60	60	60	xxx	130	120	120	xxx	3	2	1	260	190	130	180	360.00	2.78	bubble limited
90	60	60	xxx	60	60	60	xxx	150	120	120	xxx	3	2	1	300	210	150	180	360.00	2.78	bubble limited
110	60	60	xxx	60	60	60	xxx	170	120	120	xxx	3	2	1	340	230	170	180	360.00	2.78	bubble limited
130	60	60	xxx	60	60	60	xxx	190	120	120	xxx	3	2	1	380	250	190	180	380.00	2.63	delay limited
150	60	60	xxx	60	60	60	xxx	210	120	120	xxx	3	2	1	420	270	210	180	420.00	2.38	delay limited
170	60	60	xxx	60	60	60	xxx	230	120	120	xxx	3	2	1	460	290	230	180	460.00	2.17	delay limited
190	60	60	xxx	60	60	60	xxx	250	120	120	xxx	3	2	1	500	310	250	180	500.00	2.00	delay limited