All problems refer to the following flowgraph (Y = x* a0 + x@1 * b1)

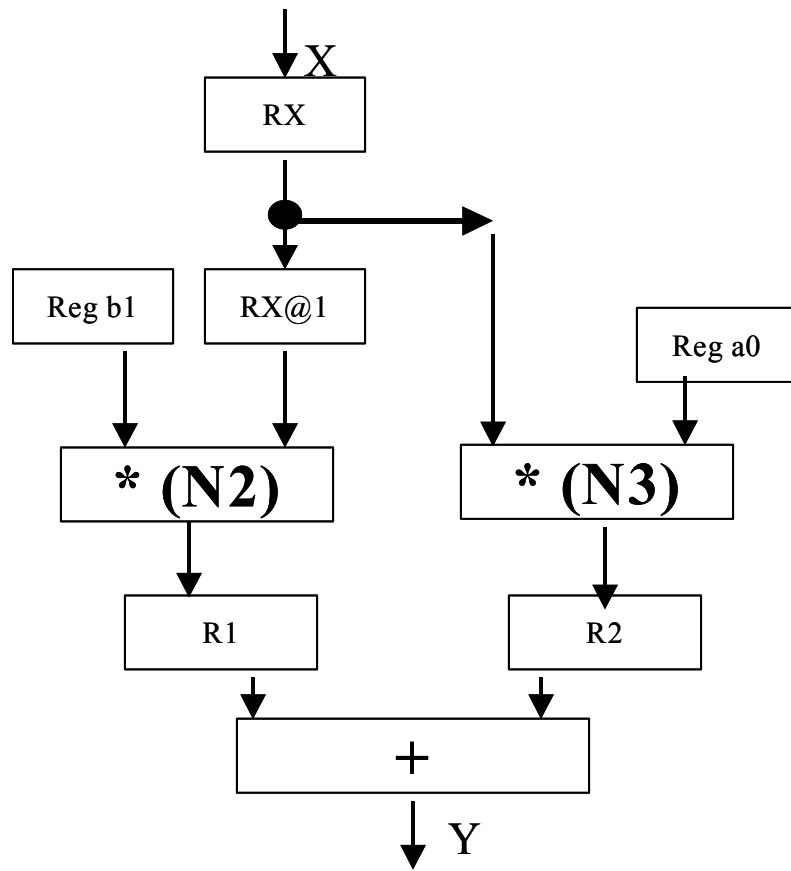**Figure 1**

N1

X

a0

X@1

b1

N3

*

N2

*

N4

+

Y
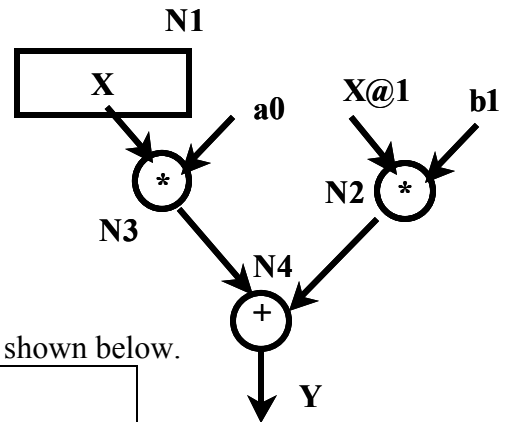
The schedule for initiation rate = 1, latency =3 and datapath is shown below.

	Sample A	Sample B	Sample C
Clk N	N1(←)		
Clk N+1	N2(*), N3(*)	N1(←)	
Clk N+2	N4(+)	N2(*), N3(*)	N1(←)
Clk N+3		N4(+)	N2(*), N3(*)
Clk N+4			N4(+)

Datapath A

X

RX

Reg b1

RX@1

Reg a0

* (N2)

* (N3)

R1

R2

+

Y

1. Assume the multiplier now has a pipeline stage, and apply this to the schedule on the previous page.

What happens to the latency?

	Sample A	Sample B	Sample C	Sample D	Sample E
Clk N	N1(←)				
Clk N+1	N2(*),N3(*)	N1(←)			
Clk N+2		N2(*),N3(*)	N1(←)		
Clk N+3	N4(+)		N2(*),N3(*)	N1(←)	
Clk N+4		N4(+)		N2(*),N3(*)	N1(←)
Clk N+5			N4(+)		N2(*),N3(*)
Clk N+6				N4(+)	
Clk N+7					N4(+)

Does the datapath need to change other than replacing the multiplier with a pipelined multiplier? Why or Why not?

No, it does not need to change since the pipeline stages add the same latency to every path.

2. Assume the delay of the multiplier is 20 ns, the adder delay is 7 ns, Tsu = 1 ns, Thd = 1 ns, TCq = 2ns

A1. What is the minimum clock period of the original datapath?

Tmult + Tcq + Tsu =   20 + 2 + 1 =   23 ns

A2. How long does it take to compute the first 10 sample values? Include pipeline startup.

3 clocks for 1 sample, then 9 clocks after that.   3 * 23 + 9*23 =   276 ns

B1.   What is the minimum clock period of the new datapath with the pipelined multiplier?

Tmult/2 + Tcq + Tsu = 10 + 2 + 1 = 13 ns
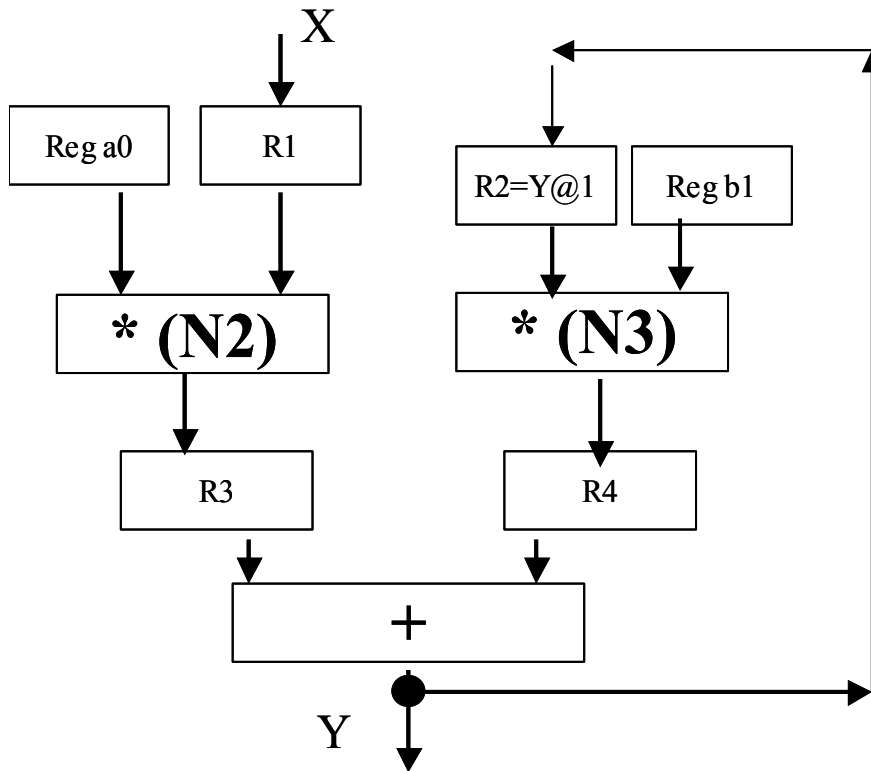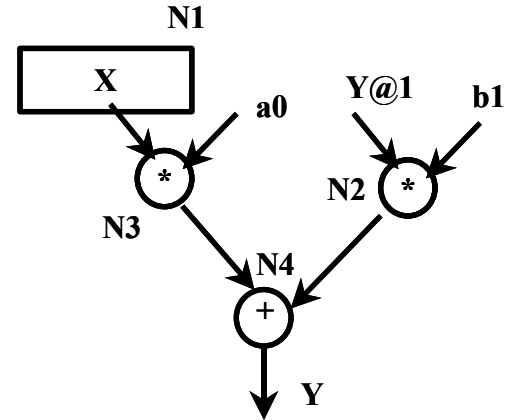

How long does it take to compute 10 sample values?

4 clocks for 1 sample, 9 clocks after that :   4 * 13 + 9 * 13 =   169 ns.

The schedule for flowgraph with the Y @1 input value is shown below.

|	Sample J	Sample J+1
Clk 1	N1	
Clk 2	N3, N2 (depends on N4 Sample J-1)	
Clk 3	N4	N1,
Clk 4		N3, **N2** **(depends on N4 sample J)**
Clk 5		N4
Clk 6		

Figure 2

3. Assume the multiplier now has a pipeline stage, and create a new schedule.   What happens to initiation rate, latency?

	Sample A	Sample B	Sample C	Sample D	Sample E
Clk N	N1				
Clk N+1	N3, N2				
Clk N+2					
Clk N+3	N4	N1			
Clk N+4		N3,N2			
Clk N+5					
Clk N+6		N4			
Clk N+7					

X

| Reg a0 | R1 |

| R2=Y@1 | Reg b1 |

| * (N2) | | * (N3) |

| R3 | | R4 |

| + |

Y
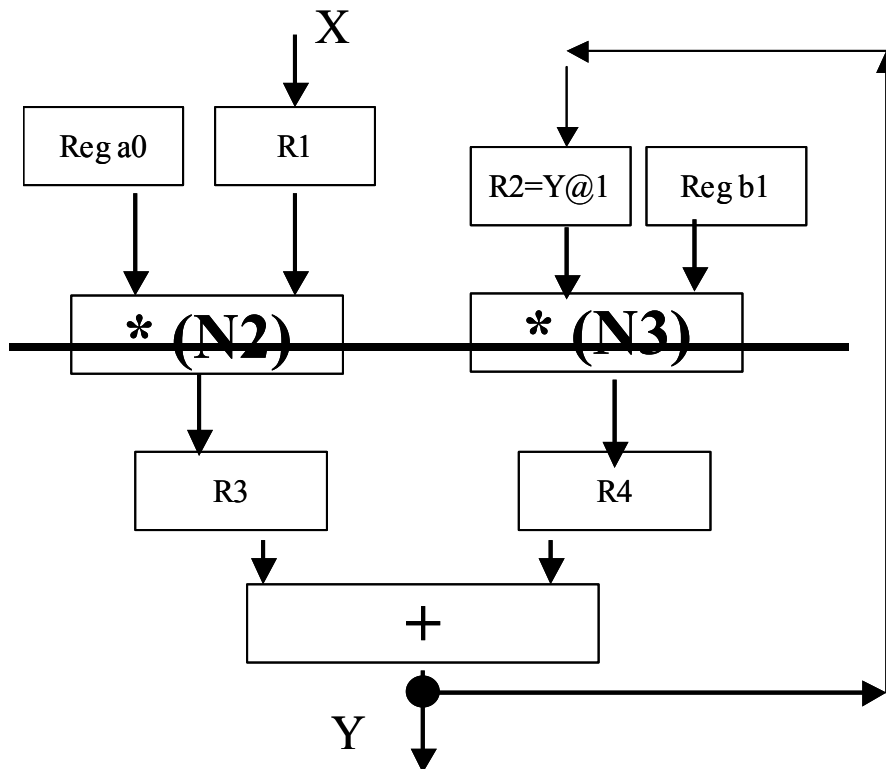
4. Assume the delay of the multiplier is 20 ns, the adder delay is 7 ns, Tsu = 1 ns, Thd = 1 ns, TCq = 2ns

A1. What is the minimum clock period of the original datapath (without pipelining)?

Tmult + Tcq + Tsu =   20 + 2 + 1 =   23 ns

A2. How long does it take to compute the first 10 sample values (without a pipelined multiplier)? Include datapath startup.

3 clocks for first sample, then 9*2 clocks after that.   3 * 23 + 9*2*23 =   483 ns

B1.   What is the minimum clock period of the new datapath with the pipelined multiplier?

Tmult/2 + Tcq + Tsu = 10 + 2 + 1 = 13 ns

 How long does it take to compute 10 sample values?

4 clocks for first sample, then 9*3 clocks after that.   4 * 13 + 9*3*13 =   403 ns

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