Digital IC Design Report

Exercise 4: Energy-Efficient Deign

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2x2 Convolution (without pipeline)

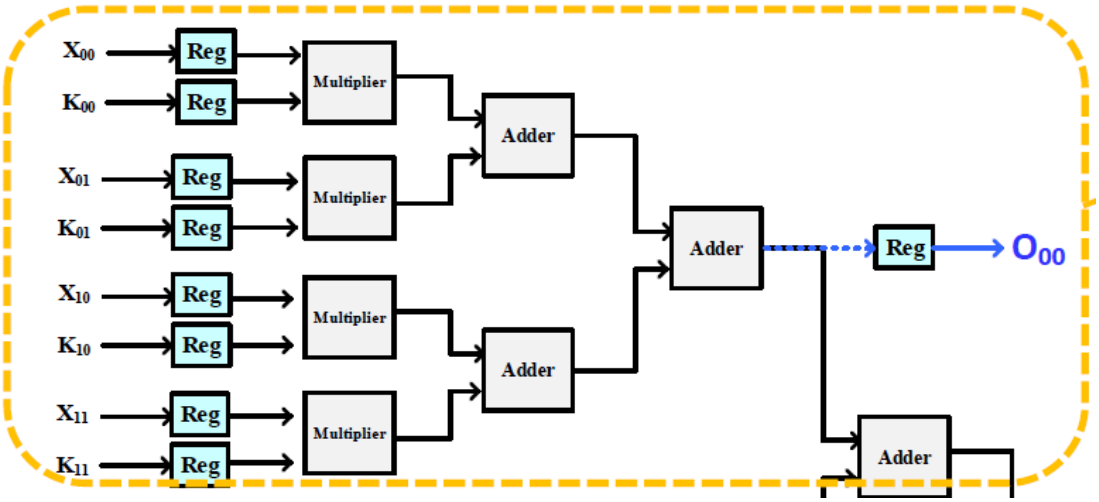

Figure 1. Schematic of 2x2 Convolution circuit

➢ HSPICE waveform

Input Pattern:

```
pattern - Notepad
File  Edit  Format  View  Help
radix   1 1 1111 1111 1111 1111 1111 1111 1111 1111
vname   rst invalid inIFM1_[3:0] inIFM2_[3:0] inIFM3_[3:0] inIFM4_[3:0] inW1_[3:0] inW2_[3:0] inW3_[3:0] inW4_[3:0]
io              i i iiii iiii iiii iiii iiii iiii iiii iiii
tunit ps
slope 10
vih 0.7
vil 0
period 1000

0 0 0000 0000 0000 0000 0000 0000 0000 0000
1 1 0000 0000 0000 0000 0000 0000 0000 0000
1 1 0011 1010 1010 1010 1010 1111 1011 1100
1 1 1010 1010 1010 1010 1010 1111 1011 1100
1 1 1110 1111 1011 1110 0111 0101 1011 0111
1 1 1000 1010 1011 0001 1101 0101 1011 1111
1 1 0010 0001 0111 0001 1101 0101 0111 0001
1 1 1000 1010 0011 0101 1110 0001 1011 1000
1 1 1000 1010 1001 1111 1101 0001 1011 1000
1 1 1000 1000 1111 0001 0111 0101 1011 0000
1 1 1001 1011 0010 0001 1000 0101 0011 0100
1 1 1001 1000 0010 0001 1001 0111 0011 0101
1 1 1000 1011 1010 0001 1001 0101 0001 0101
```

Figure 2. Pattern Vector File

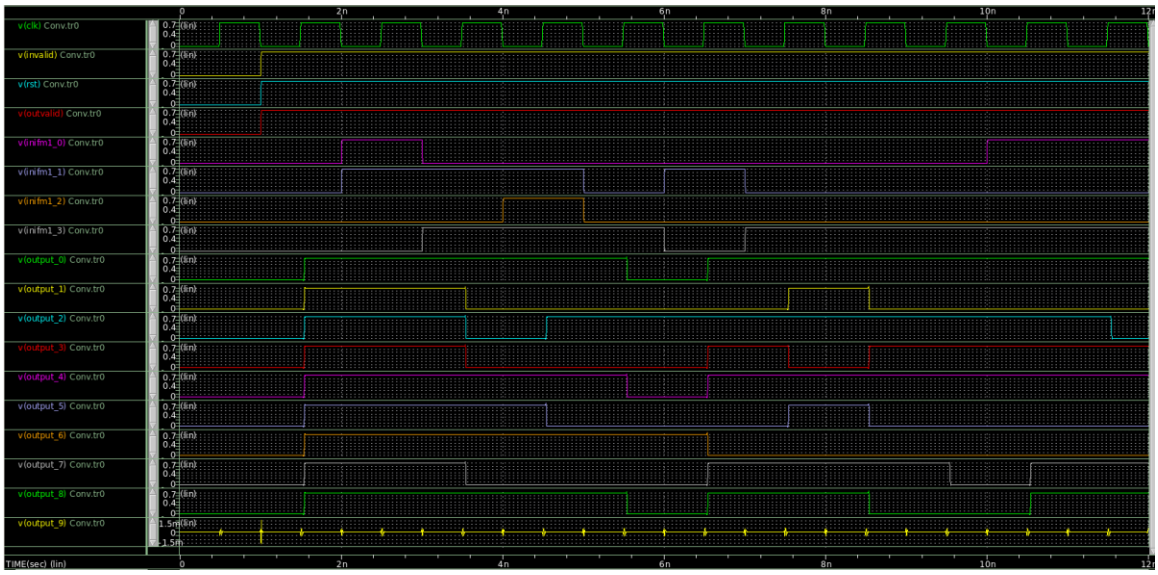

Figure 3. Waveform of 2x2 Convolution circuit

Critical Path: inIFM1_0 (r) ⟹ *output_2 (r)*

➢ Voltage Scaling

✓ <u>0.7V:</u>

```
$DATA1 SOURCE='HSPICE' VERSION='O-2018.09 linux64' PARAM_COUNT=0
.TITLE '.title conv 2x2'
 tpd              pwr              temper           alter#
  2.540e-09        4.518e-04          25.0000        1
```

Energy-Delay Product = 1.147572*10^-12

✓ 0.65V:

```
$DATA1 SOURCE='HSPICE' VERSION='O-2018.09 linux64' PARAM_COUNT=0
.TITLE '.title conv 2x2'
 tpd              pwr              temper           alter#
  2.547e-09        3.659e-04          25.0000        1
```

Energy-Delay Product = 9.319473*10^-13

✓ 0.6V:

```
$DATA1 SOURCE='HSPICE' VERSION='O-2018.09 linux64' PARAM_COUNT=0
.TITLE '.title conv 2x2'
 tpd              pwr              temper           alter#
  2.558e-09        2.877e-04          25.0000        1
```

Energy-Delay Product = 7.359366*10^-13

✓ 0.55V:

```
$DATA1 SOURCE='HSPICE' VERSION='O-2018.09 linux64' PARAM_COUNT=0
.TITLE '.title conv 2x2'
 tpd              pwr              temper           alter#
  2.574e-09        2.182e-04         25.0000         1
```

Energy-Delay Product = 5.616468*10^-13

✓ 0.5V:

```
$DATA1 SOURCE='HSPICE' VERSION='O-2018.09 linux64' PARAM_COUNT=0
.TITLE '.title conv 2x2'
 tpd              pwr              temper           alter#
  2.599e-09        1.591e-04         25.0000         1
```

Energy-Delay Product = 4.135009*10^-13

✓ 0.45V:

```
$DATA1 SOURCE='HSPICE' VERSION='O-2018.09 linux64' PARAM_COUNT=0
.TITLE '.title conv 2x2'
 tpd              pwr              temper           alter#
    failed         1.085e-04         25.0000         1
```

CIRCUIT FAIL

Ans: Minimal Energy-Delay Product appears at 0.5V, 4.135009*10^-13

2x2 Convolution (pipeline)

Figure 4. Schematic of 2x2 Convolution pipelined design

➢ HSPICE waveform

Input Pattern:

pattern_pp - Notepad

File Edit Format View Help

```
radix   1 1 1111 1111 1111 1111 1111 1111 1111 1111
vname   rst invalid inIFM1_[3:0] inIFM2_[3:0] inIFM3_[3:0] inIFM4_[3:0] inW1_[3:0] inW2_[3:0] inW3_[3:0] inW4_[3:0]
io      i i iiii iiii iiii iiii iiii iiii iiii iiii
tunit ps
slope 10
vih 0.7
vil 0
period 1000

0 0 0000 0000 0000 0000 0000 0000 0000 0000
1 1 0000 0000 0000 0000 0000 0000 0000 0000
1 1 0011 1010 1010 1010 1010 1111 1011 1100
1 1 1010 1010 1010 1010 1010 1111 1011 1100
1 1 1110 1111 1011 1110 0111 0101 1011 0111
1 1 1000 1010 1011 0001 1101 0101 1011 1111
1 1 0010 0001 0111 0001 1101 0101 0111 0001
1 1 1000 1010 0011 0101 1110 0001 1011 1000
1 1 1000 1010 1001 1111 1101 0001 1011 1000
1 1 1000 1000 1111 0001 0111 0101 1011 0000
1 1 1001 1011 0010 0001 1000 0101 0011 0100
1 1 1001 1000 0010 0001 1001 0111 0011 0101
1 1 1000 1011 1010 0001 1001 0101 0001 0101
```

Figure 5. Input pattern vector file

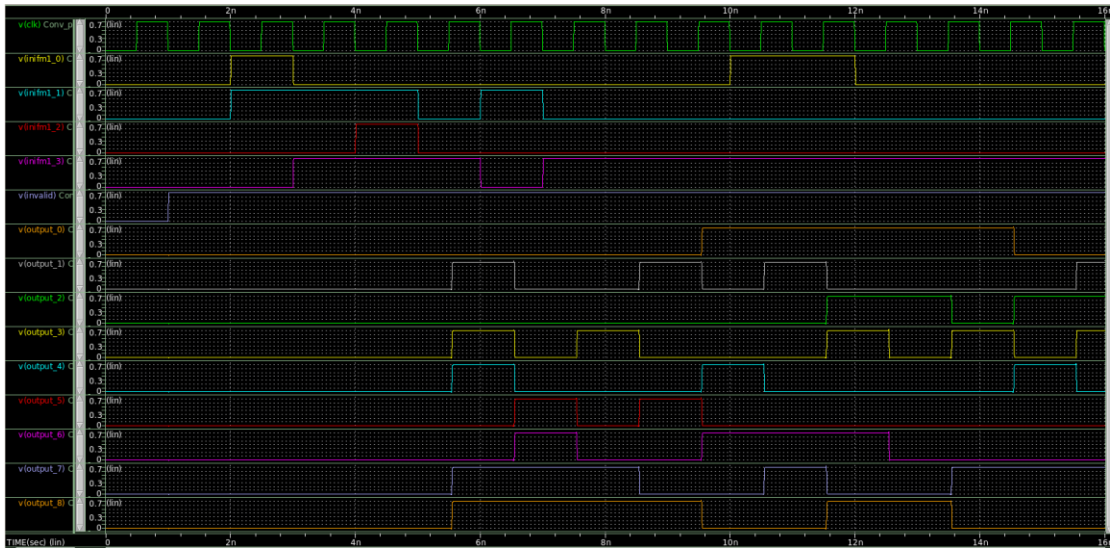

Figure 6. Waveform of 2x2 Convolution pipelined circuit

Critical Path:

Point	Incr	Path
clock clk (rise edge)	0.00	0.00
clock network delay (ideal)	0.00	0.00
PPR2_2_reg[0]/CLK (ASYNC_DFFHx1_ASAP7_75t_R)	0.00	0.00 r
PPR2_2_reg[0]/QN (ASYNC_DFFHx1_ASAP7_75t_R)	56.07	56.07 r
U400/Y (NOR2xp33_ASAP7_75t_R)	43.23	99.30 f
U868/Y (MAJIxp5_ASAP7_75t_R)	43.31	142.61 r
U909/Y (MAJIxp5_ASAP7_75t_R)	32.54	175.14 f
U924/Y (MAJIxp5_ASAP7_75t_R)	35.42	210.56 r
U1005/Y (MAJIxp5_ASAP7_75t_R)	31.25	241.81 f
U1020/Y (MAJIxp5_ASAP7_75t_R)	35.13	276.94 r
U1041/Y (MAJIxp5_ASAP7_75t_R)	31.23	308.16 f
U1042/Y (MAJIxp5_ASAP7_75t_R)	32.97	341.13 r
U1083/Y (AND2x2_ASAP7_75t_R)	25.48	366.61 r
U381/Y (NOR2xp33_ASAP7_75t_R)	14.86	381.47 f
U1084/SN (HAxp5_ASAP7_75t_R)	25.55	407.03 f
U1085/Y (NAND2xp33_ASAP7_75t_R)	11.80	418.83 r
U462/Y (NAND2xp33_ASAP7_75t_R)	11.59	430.42 f
Out_OFM_reg[8]/D (ASYNC_DFFHx1_ASAP7_75t_R)	0.00	430.42 f
data arrival time		430.42
clock clk (rise edge)	1000.00	1000.00
clock network delay (ideal)	0.00	1000.00
Out_OFM_reg[8]/CLK (ASYNC_DFFHx1_ASAP7_75t_R)	0.00	1000.00 r
library setup time	-16.27	983.73
data required time		983.73
data required time		983.73
data arrival time		-430.42
slack (MET)		553.32

Figure 7. Timing Report 2x2 Pipelined Convolution Circuit

Critical Path: n190 (r) ⟹ n371(f)

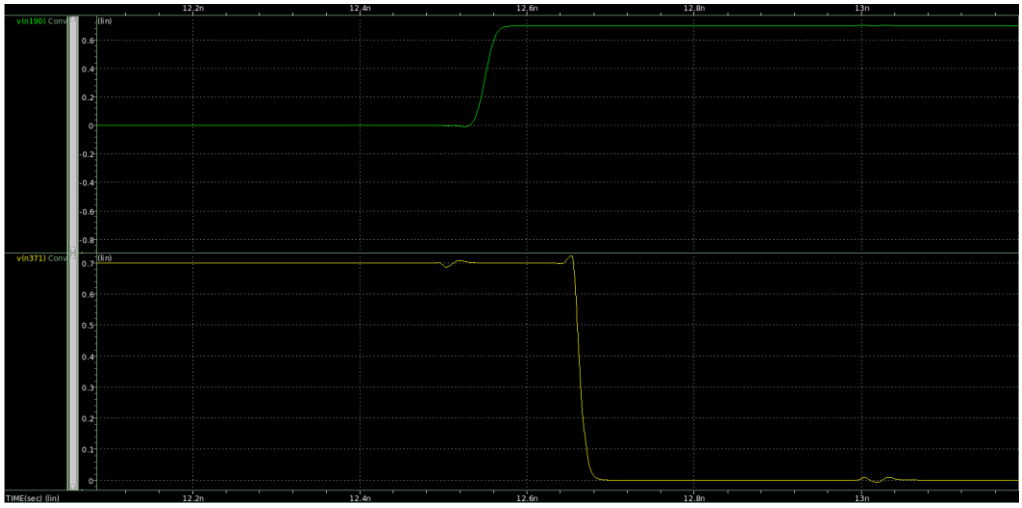

Figure 8. Rising edge of node 190 and falling edge of node 371

➢ Voltage Scaling

✓ 0.7V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tpd= 112.7391p  targ=  12.6630n   trig=  12.5502n
pwr= 227.6791u  from=   0.             to=  16.0000n
```

Energy-Delay Product = 2.5668*10^-14

✓ 0.65V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tpd= 127.6415p  targ=  12.6850n   trig=  12.5574n
pwr= 194.7061u  from=   0.             to=  16.0000n
```

Energy-Delay Product = 2.4852*10^-14

✓ 0.6V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tpd= 149.0594p  targ=  12.7167n   trig=  12.5676n
pwr= 164.4839u  from=   0.             to=  16.0000n
```

Energy-Delay Product = 2.4518*10^-14

✓ 0.55V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tpd= 181.3551p  targ=  12.7641n   trig=  12.5828n
pwr= 137.1577u  from=   0.             to=  16.0000n
```

Energy-Delay Product = 2.4874*10^-14

✓ 0.5V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tpd= 181.4802p  targ=  12.7643n   trig=  12.5828n
pwr= 137.0283u  from=   0.             to=  16.0000n
```

Energy-Delay Product = 2.48679*10^-14

✓ 0.45V:

```
****** transient analysis tnom=  25.000 temp=  25.000 ******
tpd= 181.5638p  targ=  12.7643n   trig=  12.5828n
pwr= 138.0611u  from=   0.              to=  16.0000n
```

Energy-Delay Product = 2.5066*10^-14

✓ 0.4V

CIRCUIT FAIL

Ans: The minimal energy-delay product appears at 0.6V, 2.4518*10^-14.