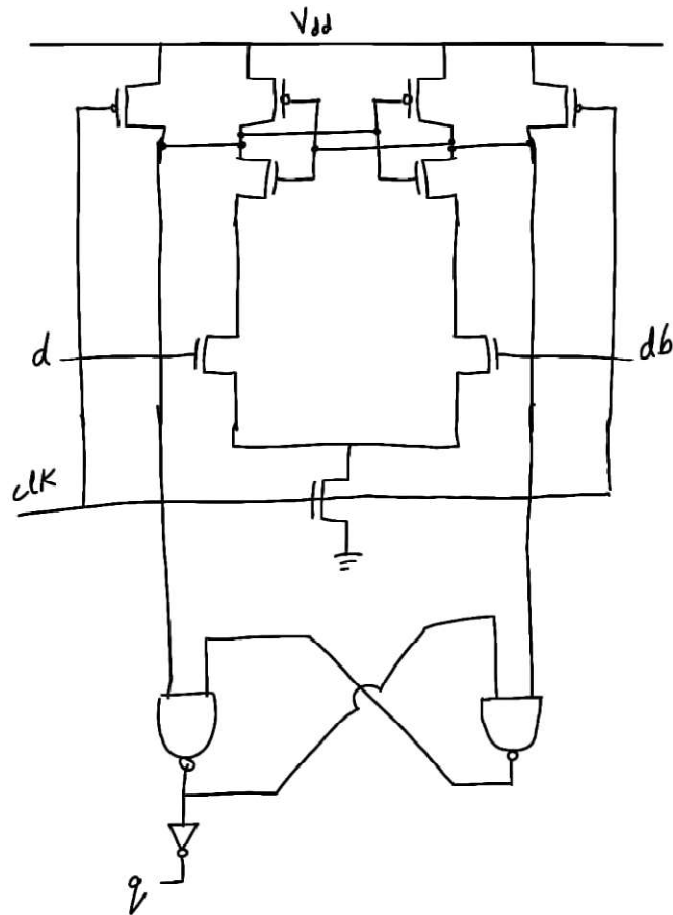**Sense Amplifier Flip-Flop**

Precharge transistors :

When clk = 0, these transistors pull internal nodes high, precharging the internal nodes before sensing starts.

Differential input pair(Data sensing)

These transistors compare input data by creating a small voltage difference between the internal nodes when clk goes high.

Cross-Coupled Inverter

Acts as a positive feedback latch to amplify small input difference into full-swing digital output.

Clock-Controlled Discharge Path

Turns ON during Clk = 1 to initiate evaluation phase and current flow.
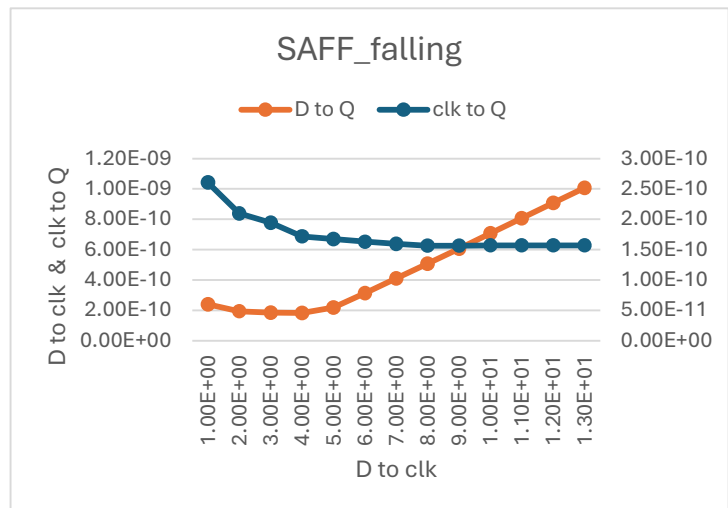
Efficient SAFF : Falling

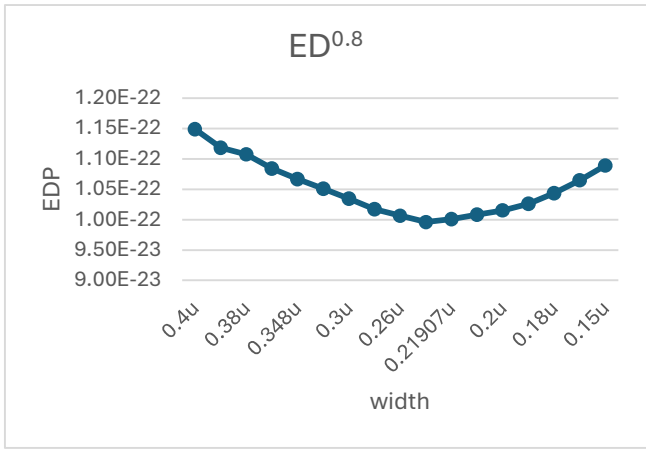| Dvalue	d to clk	clk2q	delay	power	width	Energy	EDP(PDD)
1.9335n	1.65E-11	1.52E-10	1.68E-10	4.50E-05	0.4u	7.57E-15	1.28E-24
1.935n	1.50E-11	1.53E-10	1.67E-10	4.44E-05	0.39u	7.42E-15	1.24E-24
1.9372n	1.28E-11	1.55E-10	1.67E-10	4.38E-05	0.38u	7.33E-15	1.23E-24
1.9375n	1.25E-11	1.57E-10	1.70E-10	4.17E-05	0.35u	7.09E-15	1.21E-24
1.936n	1.40E-11	1.57E-10	1.71E-10	4.05E-05	0.348u	6.93E-15	1.19E-24
1.936n	1.40E-11	1.60E-10	1.74E-10	3.86E-05	0.3205u	6.73E-15	1.17E-24
1.937n	1.30E-11	1.64E-10	1.77E-10	3.72E-05	0.3u	6.57E-15	1.16E-24
1.94n	1.00E-11	1.69E-10	1.79E-10	3.58E-05	0.28u	6.40E-15	1.14E-24
1.939n	1.10E-11	1.71E-10	1.81E-10	3.45E-05	0.26u	6.25E-15	1.13E-24
1.943n	7.00E-12	1.78E-10	1.85E-10	3.31E-05	0.24u	6.10E-15	1.13E-24
1.9432n	6.80E-12	1.83E-10	1.90E-10	3.16E-05	0.21907u	6.00E-15	1.14E-24
1.9435n	6.50E-12	1.86E-10	1.92E-10	3.10E-05	0.2107u	5.97E-15	1.15E-24
1.9436n	6.40E-12	1.89E-10	1.96E-10	3.03E-05	0.2u	5.93E-15	1.16E-24
1.9442n	5.80E-12	1.94E-10	1.99E-10	2.96E-05	0.19u	5.91E-15	1.18E-24
1.946n	4.00E-12	1.98E-10	2.04E-10	2.89E-05	0.18u	5.90E-15	1.20E-24
1.9462n	3.80E-12	2.08E-10	2.12E-10	2.76E-05	0.1601u	5.84E-15	1.24E-24
1.947n	3.00E-12	2.15E-10	2.18E-10	2.69E-05	0.15u	5.85E-15	1.27E-24

EDP falling:
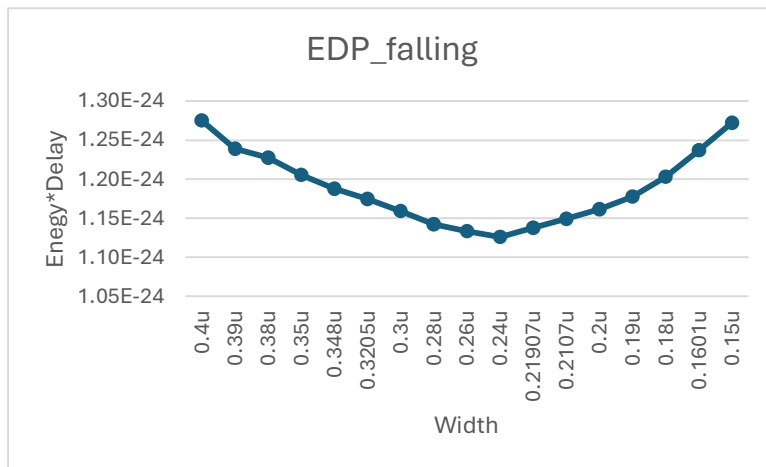
Setup time characterization : falling (Setup time : 172ps)

D value	D to clk	clk to Q	D to Q
1.97n	-2.00E-11	2.60E-10	2.40E-10
1.965n	-1.50E-11	2.10E-10	1.95E-10
1.96n	-1.00E-11	1.94E-10	1.84E-10
1.94n	1.00E-11	1.72E-10	1.82E-10
1.9n	5.00E-11	1.67E-10	2.17E-10
1.8n	1.50E-10	1.63E-10	3.13E-10
1.7n	2.50E-10	1.59E-10	4.09E-10
1.6n	3.50E-10	1.57E-10	5.07E-10
1.5n	4.50E-10	1.57E-10	6.07E-10
1.4n	5.50E-10	1.57E-10	7.07E-10
1.3n	6.50E-10	1.57E-10	8.07E-10
1.2n	7.50E-10	1.57E-10	9.07E-10
1.1n	8.50E-10	1.57E-10	1.01E-09

EDP plots :

ED⁴ — EDP vs width plot. Y-axis (EDP) ranges from 0.00E+00 to 1.40E-53. X-axis (width): 0.4u, 0.38u, 0.348u, 0.3u, 0.26u, 0.21907u, 0.2u, 0.18u, 0.15u.

ED² — EDP vs width plot. Y-axis (EDP) ranges from 0.00E+00 to 3.00E-34. X-axis (width): 0.4u, 0.38u, 0.348u, 0.3u, 0.26u, 0.21907u, 0.2u, 0.18u, 0.15u.

ED — EDP vs Width plot. Y-axis (EDP) ranges from 1.05E-24 to 1.30E-24. X-axis (Width): 0.4u, 0.38u, 0.348u, 0.3u, 0.26u, 0.21907u, 0.2u, 0.18u, 0.15u.

ED⁰·⁸ — EDP vs width plot. Y-axis (EDP) ranges from 9.00E-23 to 1.20E-22. X-axis (width): 0.4u, 0.38u, 0.348u, 0.3u, 0.26u, 0.21907u, 0.2u, 0.18u, 0.15u.

ED⁰·³ — EDP vs width plot. Y-axis (EDP) ranges from 0.00E+00 to 1.00E-17. X-axis (width): 0.4u, 0.38u, 0.348u, 0.3u, 0.26u, 0.21907u, 0.2u, 0.18u, 0.15u.

ED⁰·² — EDP vs width plot. Y-axis (EDP) ranges from 0.00E+00 to 9.00E-17. X-axis (width): 0.4u, 0.38u, 0.348u, 0.3u, 0.26u, 0.21907u, 0.2u, 0.18u, 0.15u.

Energy vs Delay : Falling

delay	power	width	Energy	EDP(PDD)	ED4	ED2	ED0.8	ED0.4	ED0.2
1.68E-10	4.50E-05	0.4u	7.57E-15	1.28E-24	6.09E-54	2.15E-34	1.15E-22	8.86E-18	8.41E-17
1.67E-10	4.44E-05	0.39u	7.42E-15	1.24E-24	5.77E-54	2.07E-34	1.12E-22	8.65E-18	8.22E-17
1.67E-10	4.38E-05	0.38u	7.33E-15	1.23E-24	5.76E-54	2.06E-34	1.11E-22	8.56E-18	8.13E-17
1.70E-10	4.17E-05	0.35u	7.09E-15	1.21E-24	5.92E-54	2.05E-34	1.08E-22	8.32E-18	7.89E-17
1.71E-10	4.05E-05	0.348u	6.93E-15	1.19E-24	5.97E-54	2.03E-34	1.07E-22	8.15E-18	7.72E-17
1.74E-10	3.86E-05	0.3205u	6.73E-15	1.17E-24	6.24E-54	2.05E-34	1.05E-22	7.96E-18	7.53E-17
1.77E-10	3.72E-05	0.3u	6.57E-15	1.16E-24	6.38E-54	2.05E-34	1.03E-22	7.79E-18	7.36E-17
1.79E-10	3.58E-05	0.28u	6.40E-15	1.14E-24	6.50E-54	2.04E-34	1.02E-22	7.61E-18	7.18E-17
1.81E-10	**3.45E-05**	**0.26u**	**6.25E-15**	1.13E-24	6.77E-54	2.06E-34	1.01E-22	7.47E-18	7.04E-17
1.85E-10	3.31E-05	0.24u	6.10E-15	1.13E-24	7.08E-54	2.08E-34	9.96E-23	7.33E-18	6.90E-17
1.90E-10	3.16E-05	0.21907u	6.00E-15	1.14E-24	7.76E-54	2.16E-34	1.00E-22	7.27E-18	6.82E-17
1.92E-10	3.10E-05	0.2107u	5.97E-15	1.15E-24	8.18E-54	2.21E-34	1.01E-22	7.27E-18	6.81E-17
1.96E-10	3.03E-05	0.2u	5.93E-15	1.16E-24	8.71E-54	2.27E-34	1.02E-22	7.26E-18	6.79E-17
1.99E-10	2.96E-05	0.19u	5.91E-15	1.18E-24	9.34E-54	2.35E-34	1.03E-22	7.27E-18	6.78E-17
2.04E-10	2.89E-05	0.18u	5.90E-15	1.20E-24	1.02E-53	2.46E-34	1.04E-22	7.30E-18	6.80E-17
2.12E-10	2.76E-05	0.1601u	5.84E-15	1.24E-24	1.18E-53	2.62E-34	1.06E-22	7.31E-18	6.78E-17
2.18E-10	2.69E-05	0.15u	5.85E-15	1.27E-24	1.31E-53	2.77E-34	1.09E-22	7.38E-18	6.83E-17

ED^4	ED^2	ED	ED$^{0.8}$	ED$^{0.6}$	ED$^{0.6}$
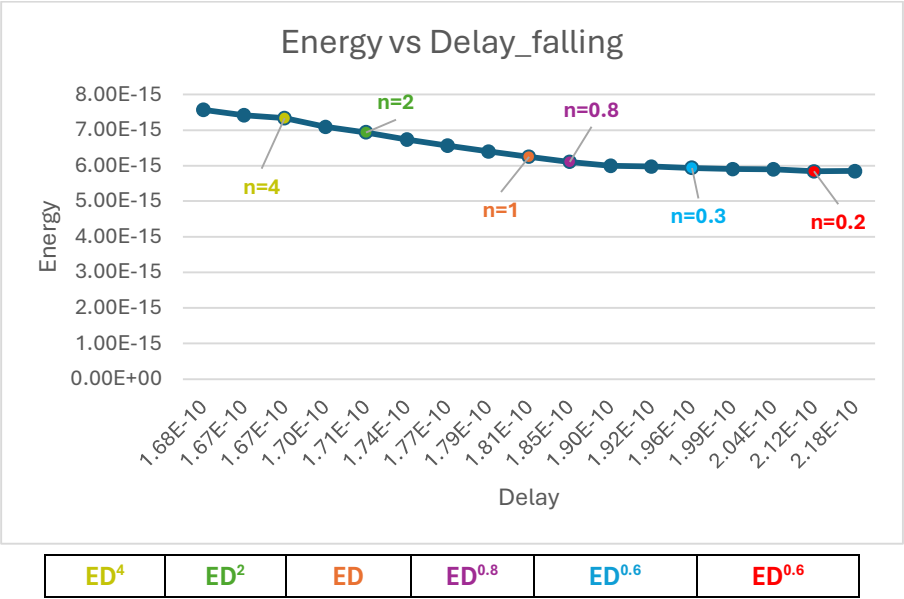
Rising :

| Dvalue	d to clk	clk2q	delay	power	width	Energy	EDP(PDD)
1.9415n	5.85E-11	8.95E-11	1.48E-10	1.44E-04	1.9u	2.13E-14	3.15E-24
1.9395n	6.05E-11	8.72E-11	1.48E-10	1.31E-04	1.7u	1.93E-14	2.85E-24
1.936n	6.40E-11	8.53E-11	1.49E-10	1.18E-04	1.505u	1.76E-14	2.63E-24
1.931n	6.90E-11	8.38E-11	1.53E-10	1.04E-04	1.3u	1.59E-14	2.43E-24
1.926n	7.40E-11	8.29E-11	1.57E-10	9.10E-05	1.1u	1.43E-14	2.24E-24
1.92n	8.00E-11	8.27E-11	1.63E-10	7.70E-05	0.8901u	1.25E-14	2.04E-24
1.91n	9.00E-11	8.53E-11	1.75E-10	5.80E-05	0.608u	1.02E-14	1.78E-24
1.91n	9.00E-11	8.82E-11	1.78E-10	5.10E-05	0.505u	9.10E-15	1.62E-24
1.91n	9.00E-11	8.96E-11	1.80E-10	4.87E-05	0.47u	8.74E-15	1.57E-24
1.911n	8.90E-11	9.01E-11	1.79E-10	4.80E-05	0.46u	8.60E-15	1.54E-24
1.91n	9.00E-11	9.11E-11	1.81E-10	4.67E-05	0.44u	8.45E-15	1.53E-24
1.91n	9.00E-11	9.28E-11	1.83E-10	4.47E-05	0.4105u	8.17E-15	1.49E-24
1.907n	9.30E-11	1.03E-10	1.96E-10	3.71E-05	0.3u	7.26E-15	1.42E-24
1.908n	9.20E-11	1.05E-10	1.97E-10	3.58E-05	0.28u	7.06E-15	1.39E-24
1.908n	**9.20E-11**	**1.09E-10**	**2.01E-10**	**3.44E-05**	**0.26u**	**6.90E-15**	**1.38E-24**
1.906n	9.40E-11	1.12E-10	2.06E-10	3.30E-05	0.24u	6.82E-15	1.41E-24
1.9n	1.00E-10	1.17E-10	2.13E-10	3.15E-05	0.21907u	6.70E-15	1.42E-24
1.9n	1.00E-10	1.19E-10	2.19E-10	3.11E-05	0.2107u	6.80E-15	1.49E-24
1.9n	1.00E-10	1.22E-10	2.22E-10	3.03E-05	0.2u	6.73E-15	1.49E-24
1.902n	1.25E-10	1.25E-10	2.23E-10	2.96E-05	0.19u	6.62E-15	1.48E-24
1.9n	1.00E-10	1.29E-10	2.26E-10	2.90E-05	0.18u	6.56E-15	1.49E-24
1.9n	1.00E-10	1.37E-10	2.37E-10	2.70E-05	0.1601u	6.41E-15	1.52E-24

EDP : rising
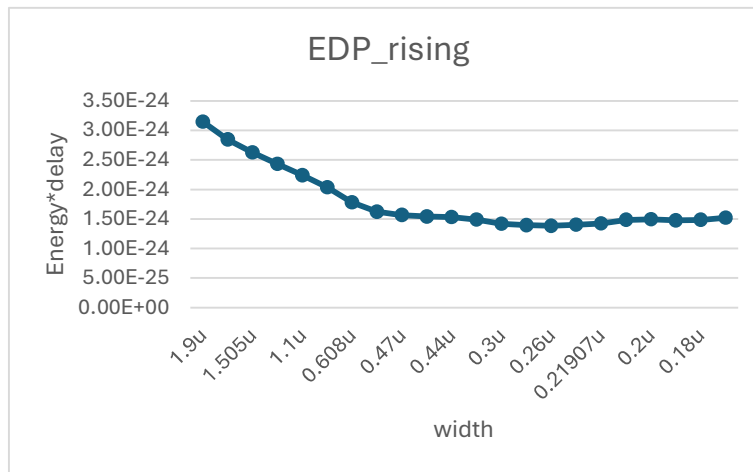
Setup time characterization : rising (Setup time : 108ps)

D value	D to clk	clk to Q	D to Q
2.008n	-8.00E-12	1.59E-10	1.51E-10
2.005n	-5.00E-12	1.34E-10	1.29E-10
2.002n	-2.00E-12	1.22E-10	1.20E-10
2n	0.00E+00	1.17E-10	1.17E-10
1.97n	3.00E-11	1.11E-10	1.41E-10
1.96n	4.00E-11	1.11E-10	1.51E-10
1.94n	6.00E-11	1.10E-10	1.70E-10
1.92n	8.00E-11	1.09E-10	1.89E-10
1.9n	1.00E-10	**1.08E-10**	2.08E-10
1.85n	1.50E-10	1.06E-10	2.56E-10
1.8n	2.00E-10	1.05E-10	3.05E-10
1.75n	2.50E-10	1.04E-10	3.54E-10
1.7n	3.00E-10	1.02E-10	4.02E-10
1.6n	4.00E-10	9.86E-11	4.98E-10
1.5n	5.00E-10	9.86E-11	5.99E-10
1.4n	6.00E-10	9.86E-11	6.99E-10
1.3n	7.00E-10	9.86E-11	7.99E-10
1.2n	8.00E-10	9.86E-11	8.99E-10
1.1n	9.00E-10	9.86E-11	9.99E-10
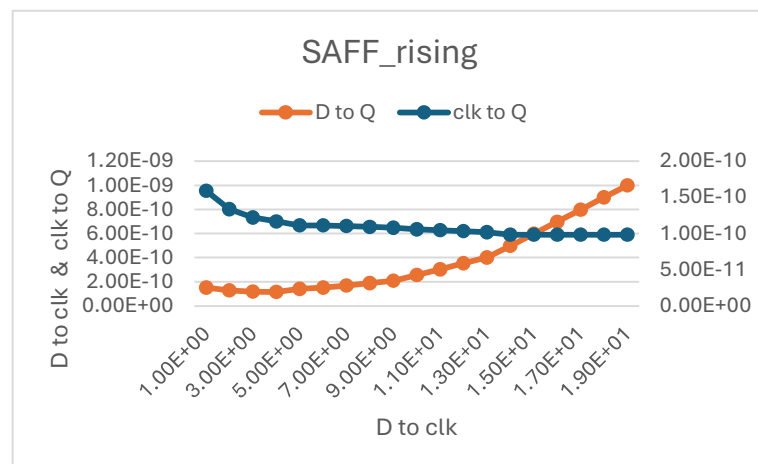
EDP plots :
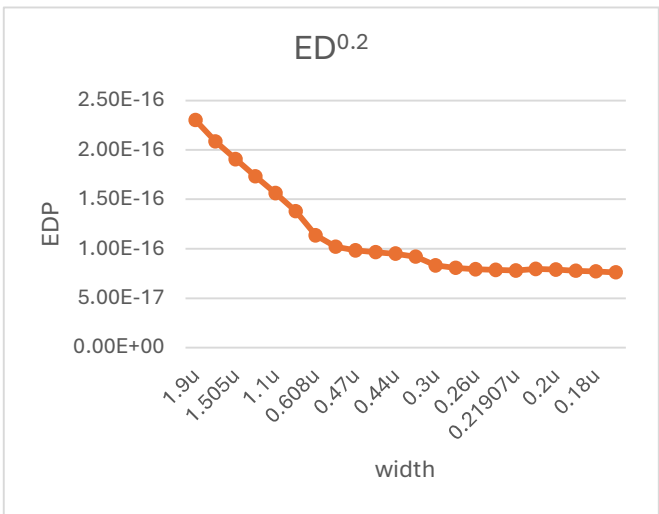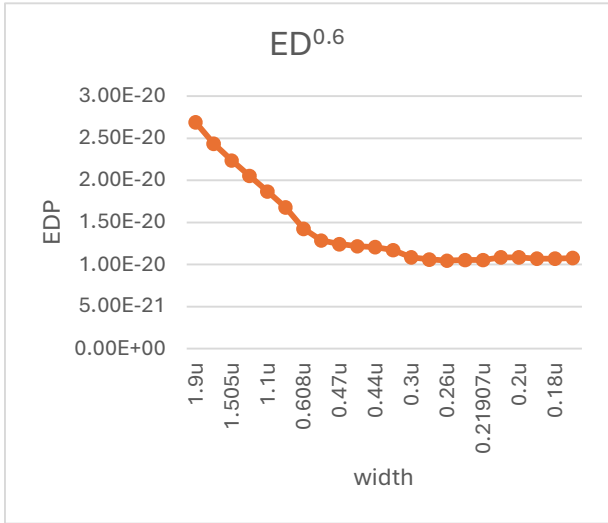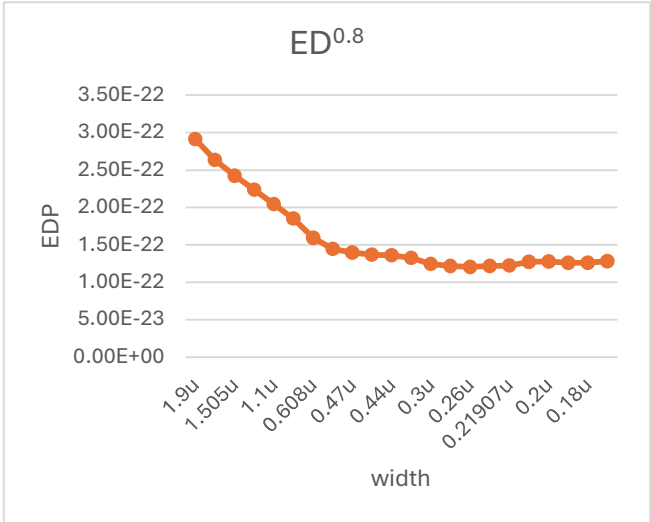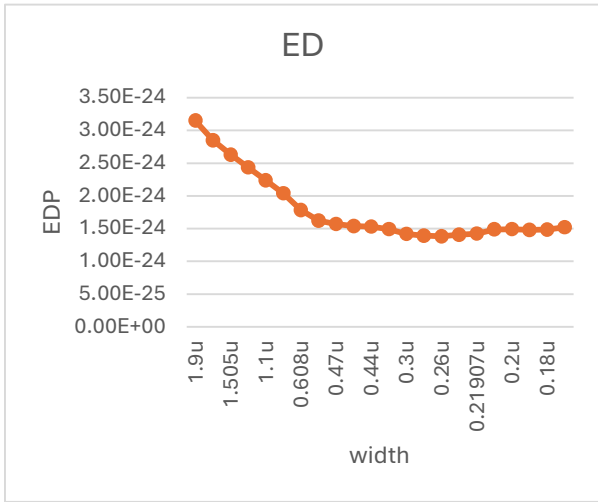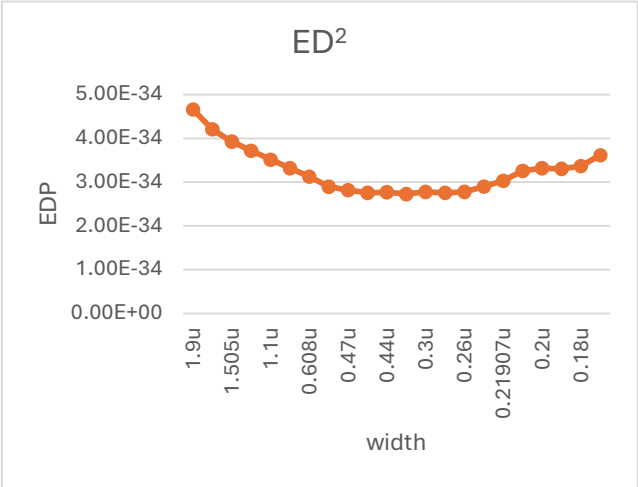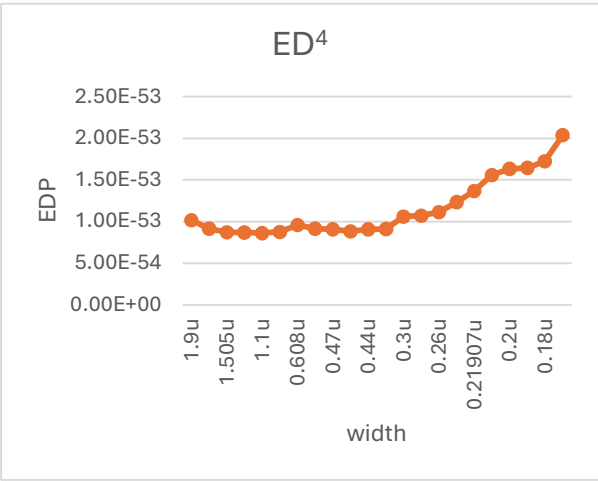
Energy vs Delay : rising

delay	power	width	Energy	EDP(PDD)	ED4	ED2	ED0.8	ED0.6	ED0.2
1.48E-10	1.44E-04	1.9u	2.13E-14	3.15E-24	1.02E-53	4.66E-34	2.91E-22	2.69E-20	2.30E-16
1.48E-10	1.31E-04	1.7u	1.93E-14	2.85E-24	9.17E-54	4.21E-34	2.63E-22	2.44E-20	2.08E-16
1.49E-10	1.18E-04	1.505u	1.76E-14	2.63E-24	8.75E-54	3.92E-34	2.42E-22	2.24E-20	1.90E-16
1.53E-10	1.04E-04	1.3u	1.59E-14	2.43E-24	8.69E-54	3.72E-34	2.24E-22	2.05E-20	1.73E-16
1.57E-10	9.10E-05	1.1u	1.43E-14	2.24E-24	8.64E-54	3.51E-34	2.05E-22	1.87E-20	1.56E-16
1.63E-10	7.70E-05	0.8901u	1.25E-14	2.04E-24	8.78E-54	3.32E-34	1.85E-22	1.68E-20	1.38E-16
1.75E-10	5.80E-05	0.608u	1.02E-14	1.78E-24	9.61E-54	3.13E-34	1.59E-22	1.42E-20	1.14E-16
1.78E-10	5.10E-05	0.505u	9.10E-15	1.62E-24	9.18E-54	2.89E-34	1.44E-22	1.29E-20	1.02E-16
1.80E-10	4.87E-05	0.47u	8.74E-15	1.57E-24	9.09E-54	2.82E-34	1.40E-22	1.24E-20	9.83E-17
1.79E-10	4.80E-05	0.46u	8.60E-15	1.54E-24	8.84E-54	2.76E-34	1.37E-22	1.22E-20	9.66E-17
1.81E-10	4.67E-05	0.44u	8.45E-15	1.53E-24	9.08E-54	2.77E-34	1.36E-22	1.21E-20	9.52E-17
1.83E-10	4.47E-05	0.4105u	8.17E-15	1.49E-24	9.13E-54	2.73E-34	1.32E-22	1.17E-20	9.21E-17
1.96E-10	3.71E-05	0.3u	7.26E-15	1.42E-24	1.06E-53	2.78E-34	1.24E-22	1.09E-20	8.31E-17
1.97E-10	3.58E-05	0.28u	7.06E-15	1.39E-24	1.07E-53	2.75E-34	1.22E-22	1.06E-20	8.09E-17
2.01E-10	3.44E-05	0.26u	6.90E-15	1.38E-24	1.12E-53	2.78E-34	1.20E-22	1.05E-20	7.93E-17
2.06E-10	3.30E-05	0.24u	6.82E-15	1.41E-24	1.23E-53	2.90E-34	1.22E-22	1.05E-20	7.88E-17
2.13E-10	3.15E-05	0.21907u	6.70E-15	1.42E-24	1.37E-53	3.03E-34	1.22E-22	1.05E-20	7.79E-17
2.19E-10	3.11E-05	0.2107u	6.80E-15	1.49E-24	1.56E-53	3.26E-34	1.27E-22	1.09E-20	7.95E-17
2.22E-10	3.03E-05	0.2u	6.73E-15	1.49E-24	1.64E-53	3.32E-34	1.27E-22	1.09E-20	7.90E-17
2.23E-10	2.96E-05	0.19u	6.62E-15	1.48E-24	1.65E-53	3.30E-34	1.26E-22	1.07E-20	7.77E-17
2.26E-10	2.90E-05	0.18u	6.56E-15	1.49E-24	1.73E-53	3.36E-34	1.26E-22	1.07E-20	7.72E-17
2.37E-10	2.70E-05	0.1601u	6.41E-15	1.52E-24	2.04E-53	3.62E-34	1.28E-22	1.08E-20	7.62E-17
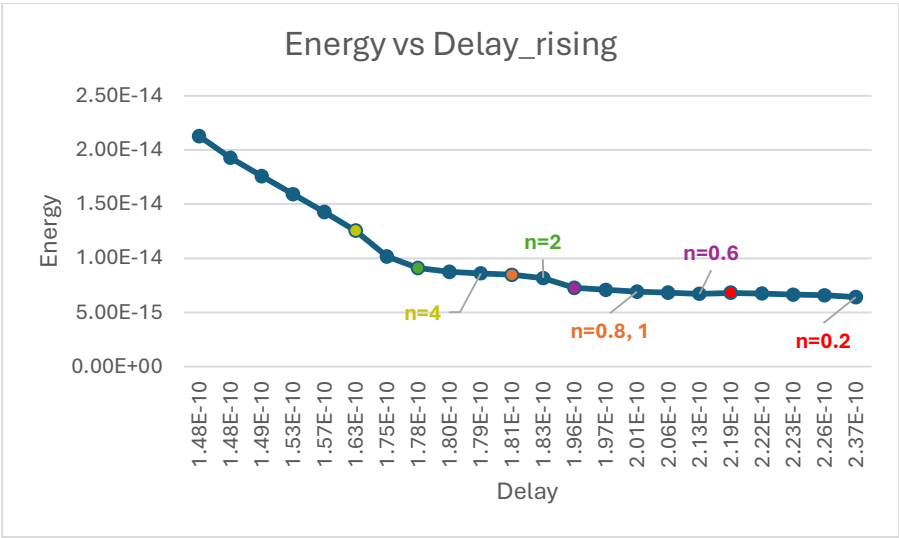
| ED^4 | ED^2 | ED , $ED^{0.8}$ | $ED^{0.6}$ | $ED^{0.2}$ |

Power vs Activity factor :

activity factor	power
0.1	2.41E-05
0.2	2.65E-05
0.3	2.93E-05
0.4	3.19E-05
0.5	3.45E-05
slope	2.60E-05
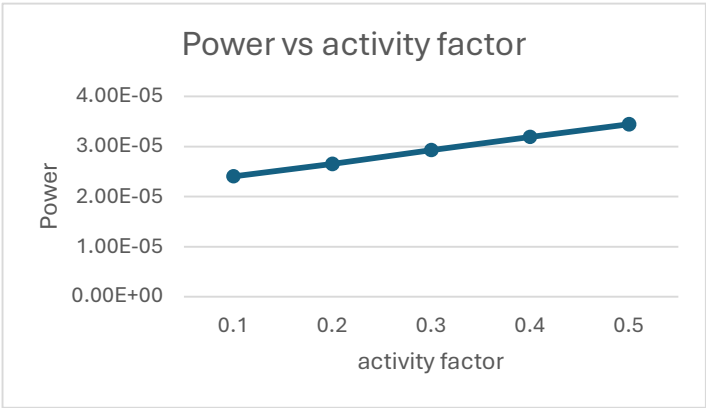
SAFF power :

clk, data	Static power
0,0	6.81E-09
0,1	1.02E-08
1,0	9.64E-09
1,1	1.28E-08
Avg =	9.87E-09
total power	3.45E-05

clk	data switching power
0	1.65E-06
1	2.89E-06
Avg=	2.27E-06
Rswitching	3.22E-05

data	clk power
0	2.06E-05
1	2.11E-05
Avg=	2.08E-05

The efficient circuit i.e. the worst case is in rising transition in terms of EDP.

Comparison of MSFF and SAFF:

| | MSFF | | | | | | SAFF | | | | |
	Dvalue	setup	clk2q	delay	power	Energy	Dvalue	setup	clk2q	delay	power	Energy
170ps	1.874n	7.60E-11	9.49E-11	1.71E-10	1.71E-04	2.92E-14	1.9375n	1.25E-11	1.57E-10	1.70E-10	4.17E-05	7.09E-15
175ps	1.873n	7.70E-11	1.03E-10	1.76E-10	1.53E-04	2.69E-14	1.936n	1.40E-11	1.60E-10	1.74E-10	3.86E-05	6.73E-15
180ps	1.873n	7.70E-11	1.03E-10	1.80E-10	1.46E-04	2.62E-14	1.94n	1.00E-11	1.69E-10	1.79E-10	3.51E-05	6.27E-15
185ps	1.872n	7.80E-11	1.06E-10	1.84E-10	1.38E-04	2.54E-14	1.943n	7.00E-12	1.78E-10	1.85E-10	3.31E-05	6.10E-15
190ps	1.871n	7.90E-11	1.10E-10	1.89E-10	1.30E-04	2.45E-14	1.9432n	6.80E-12	1.83E-10	1.90E-10	3.16E-05	6.00E-15
195ps	1.87n	8.00E-11	1.16E-10	1.96E-10	1.21E-04	2.38E-14	1.9436n	6.40E-12	1.89E-10	1.96E-10	3.03E-05	5.93E-15
200ps	1.87n	8.00E-11	1.19E-10	1.99E-10	1.18E-04	2.36E-14	1.9442n	5.80E-12	1.94E-10	1.99E-10	2.96E-05	5.91E-15
205ps	1.869n	8.10E-11	1.23E-10	2.04E-10	1.13E-04	2.30E-14	1.946n	4.00E-12	1.98E-10	2.04E-10	2.89E-05	5.90E-15
210ps	1.868n	8.20E-11	1.27E-10	2.09E-10	1.10E-04	2.29E-14	1.9462n	3.80E-12	2.08E-10	2.11E-10	2.76E-05	5.83E-15
220ps	1.866n	8.40E-11	1.36E-10	2.20E-10	1.02E-04	2.24E-14	1.947n	3.00E-12	2.15E-10	2.19E-10	2.61E-05	5.70E-15

Energy for different delays
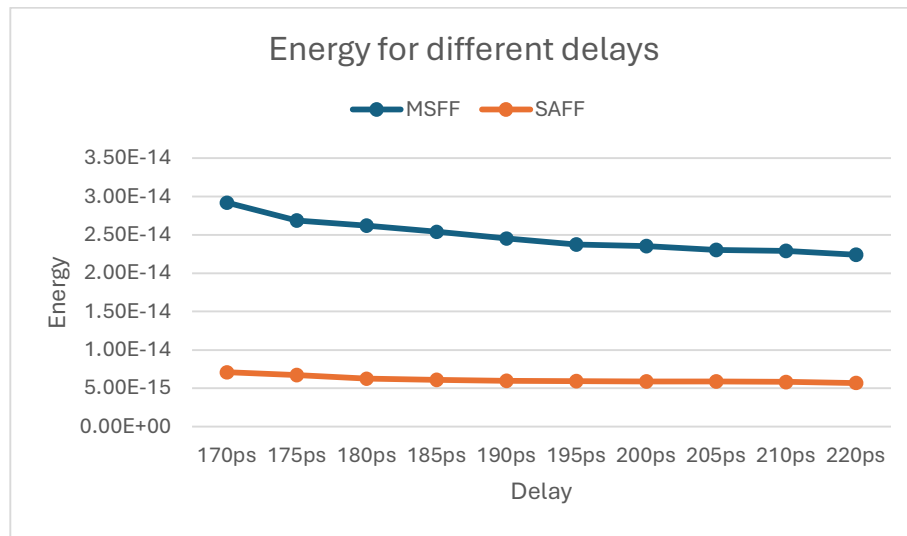
Power vs Activity factor of MSFF and SAFF:

activity factor	MSFF power	SAFF power
0.1	7.30E-05	2.41E-05
0.2	8.79E-05	2.65E-05
0.3	9.94E-05	2.93E-05
0.4	1.14E-04	3.19E-05
0.5	1.34E-04	3.45E-05
slope	1.52E-04	2.60E-05

Power vs activity factor