



UNIVERSITATEA TEHNICĂ
DIN CLUJ-NAPOCA

CANDO-EPE 2020



Facultatea de Electronică, Telecomunicații
și Tehnologia Informației

Implementation of Parallel PSO for Synchronous Step-down Converter for Laser Diodes

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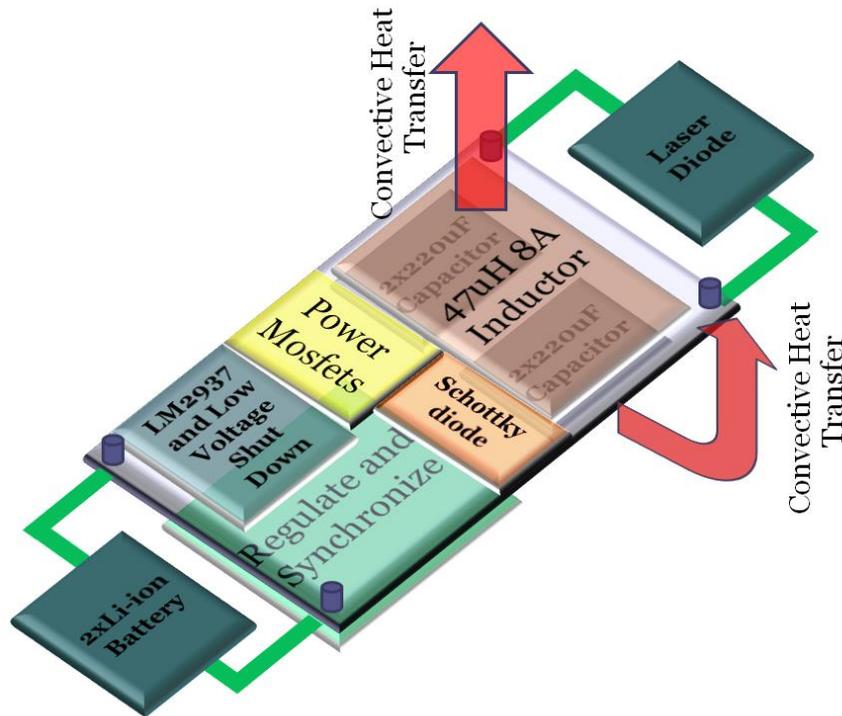


Shown Task

- Implementation and validation for PSO (Particle Swarm Optimization) as well as for synchronous DC/DC step-down converter using Matlab/Simulink;
- Implementation of synchronizing circuit and automatic shut-down;
- Temperature prediction for several components;
- Thermal runaway modeling;
- Regulator tuning using PSO;
- DC/DC converter worst case evaluation.
- PCB prototype layout implementation;

Result

Block Diagram



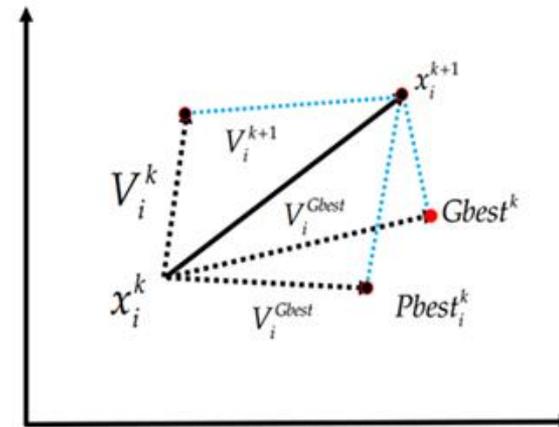
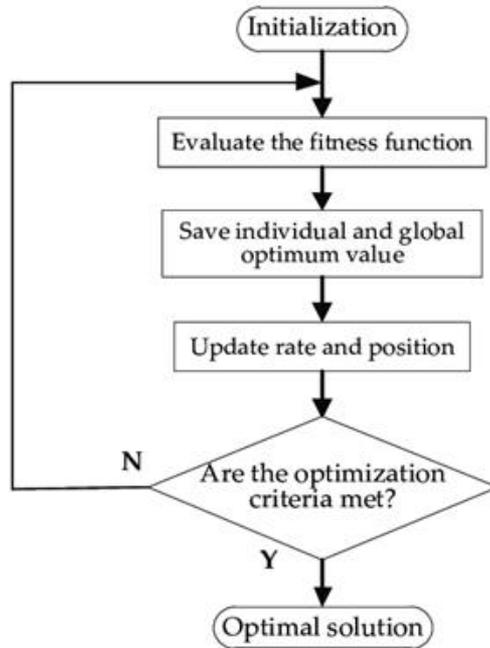
Result

■ Converter Parameters

Name	Value
Input Voltage Range	6.5 ... 10 [V]
Dimensions	35x14 [mm]
Shutdown and Turn On Voltage	6 [V], 6.5 [V] respectively
Current Setting	3 ... 5.5 [A]
Transient Response Time	100 [ms]
Controller Type	PI
K_p (after optimization)	98.38
K_p (implemented)	100
K_i (after optimization)	931.7
K_i (implemented)	1000
Overall Efficiency	88.4 – 93.5 [%]
Frequency	100 [kHz]
Inductor Internal Resistance	100 [m Ω]
Capacitor ESR	15 [m Ω]

Parallel PSO

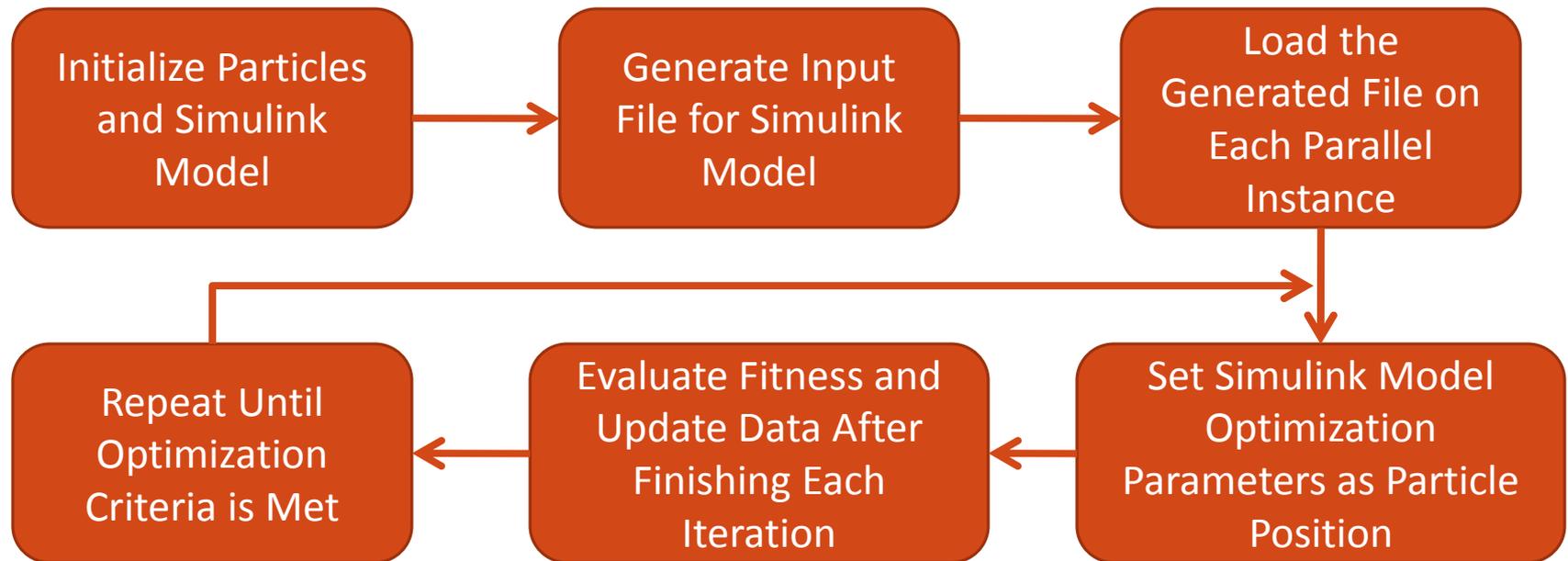
Principles





Parallel PSO

Principles

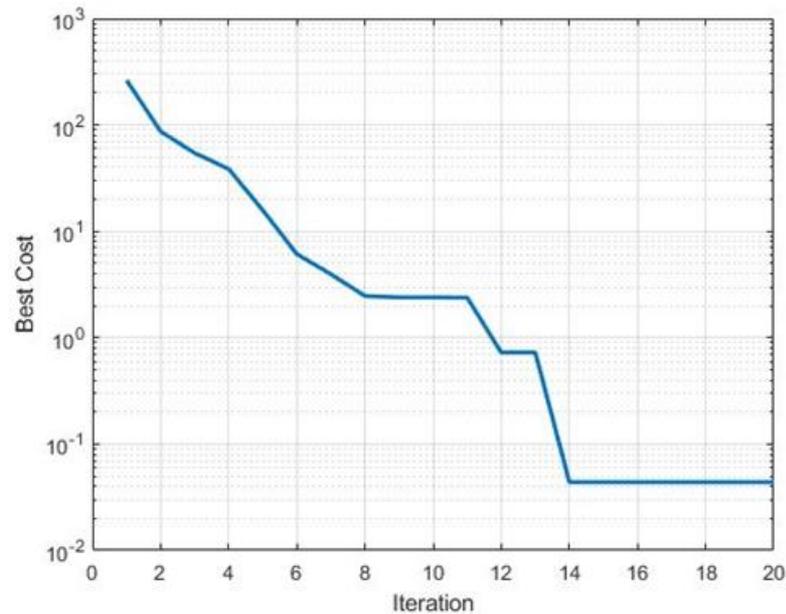




Parallel PSO

■ Optimization Examples

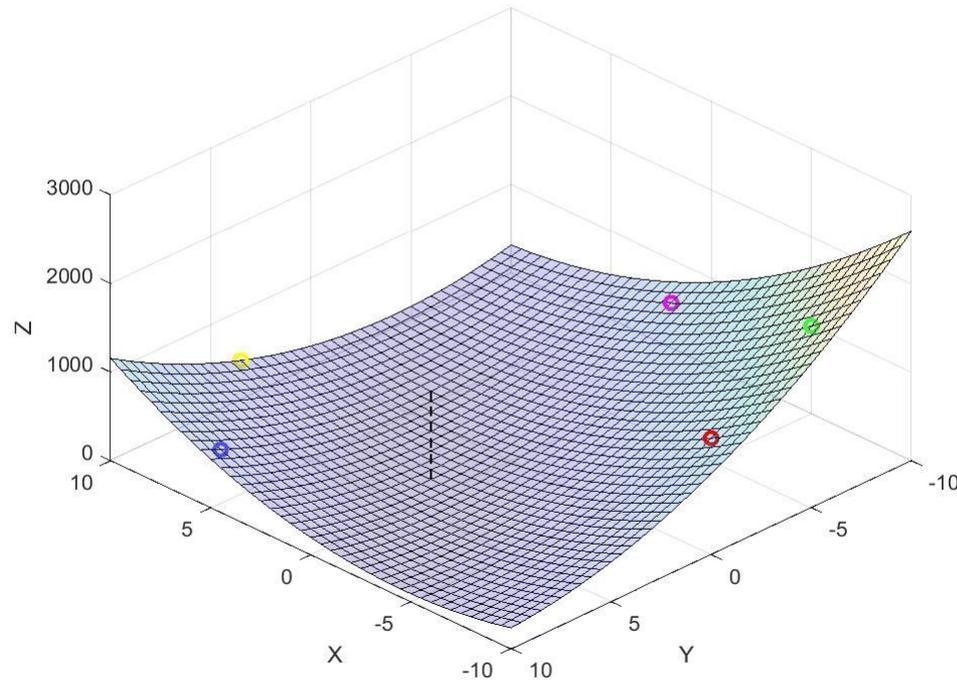
$$f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2 \quad f(1, 3) = 0$$



Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

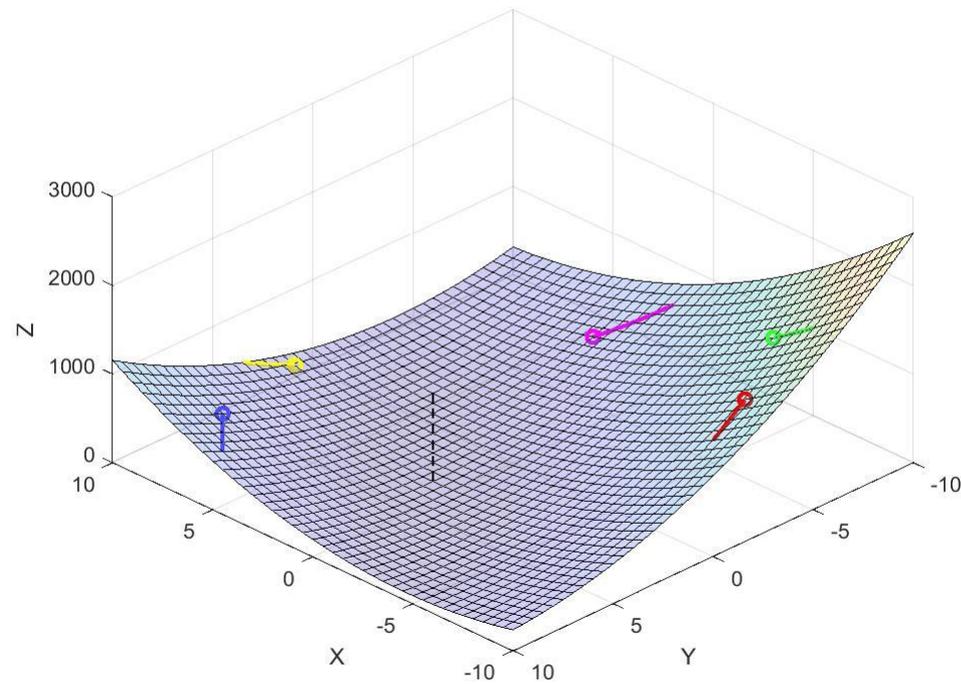
Iteration	Global Best
0	-



Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

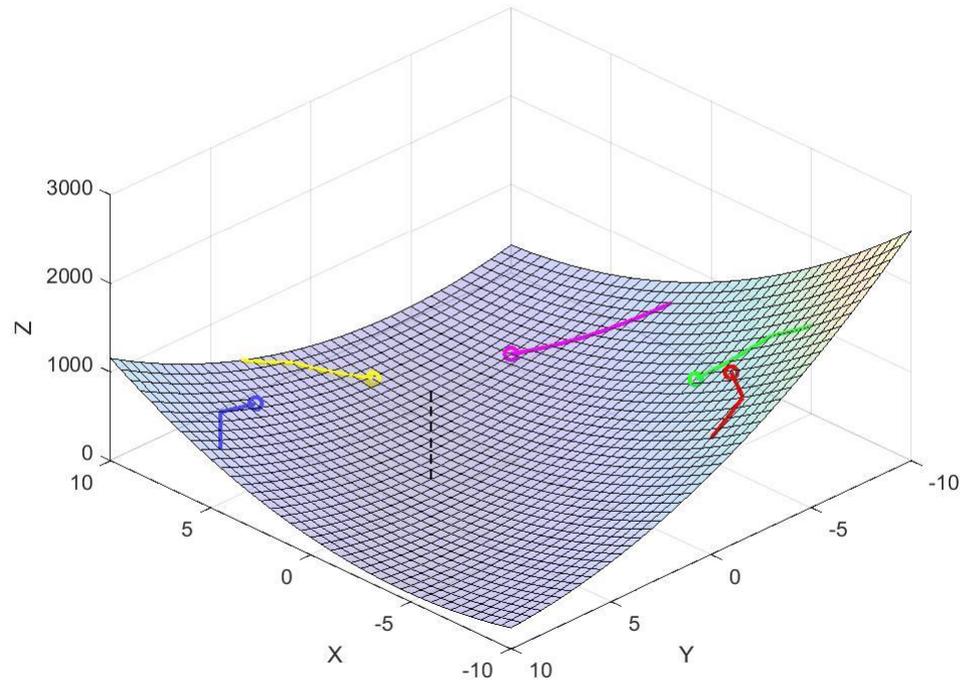
Iteration	Global Best
1	263.5184



Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

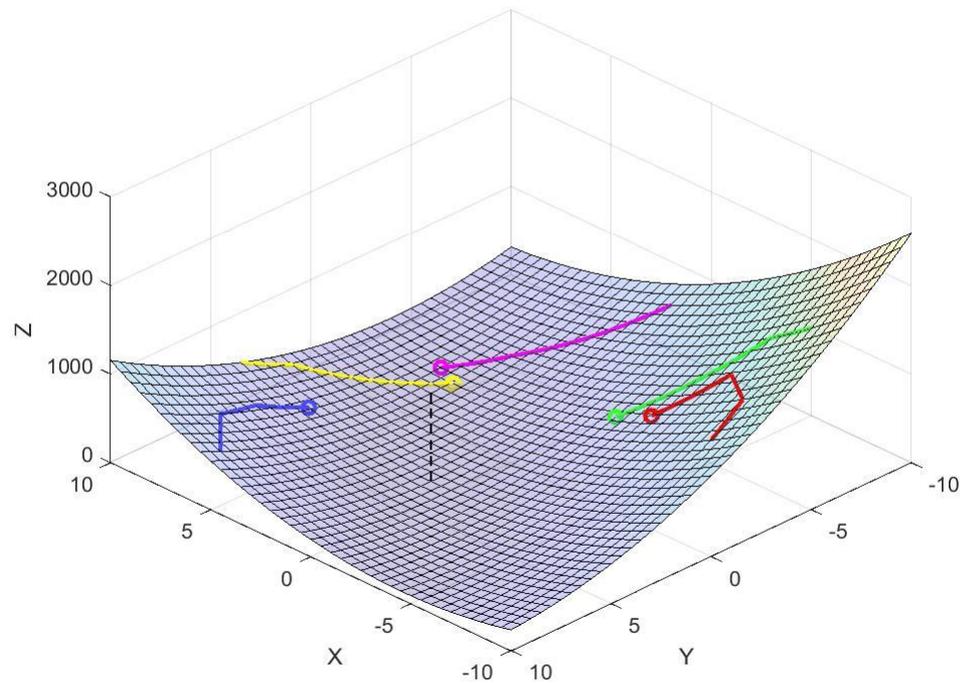
Iteration	Global Best
2	86.9842



Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

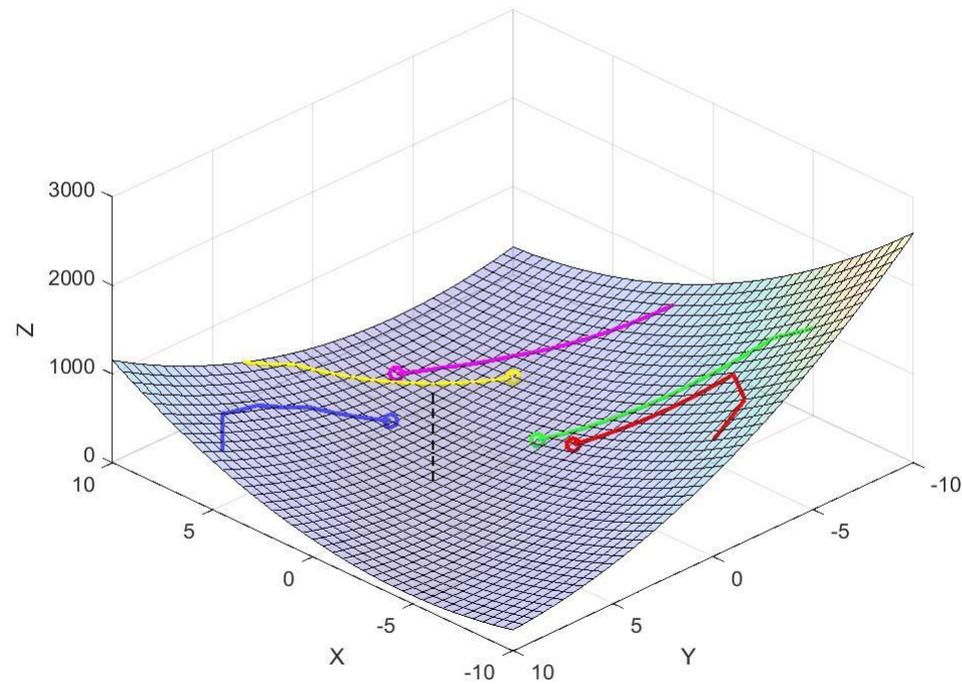
Iteration	Global Best
3	54.4501



Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

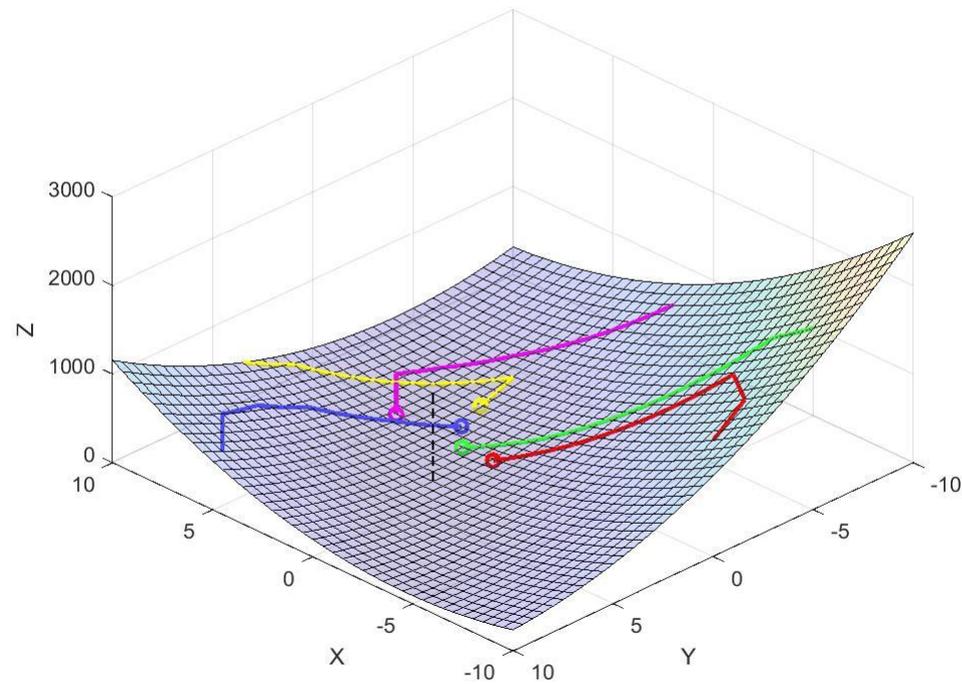
Iteration	Global Best
4	38.5546



Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

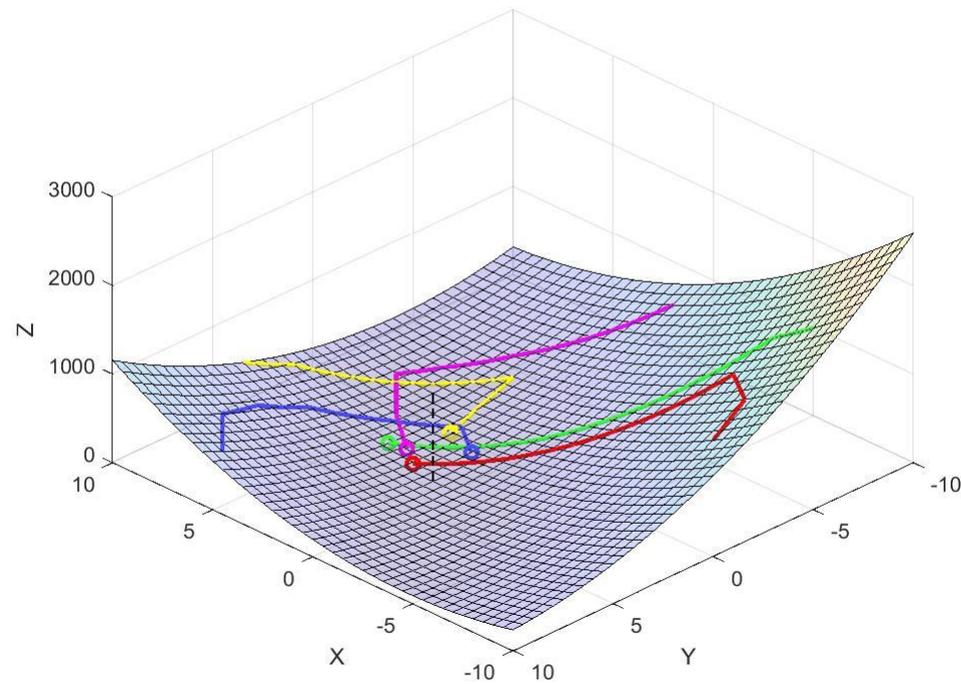
Iteration	Global Best
5	15.7912



Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

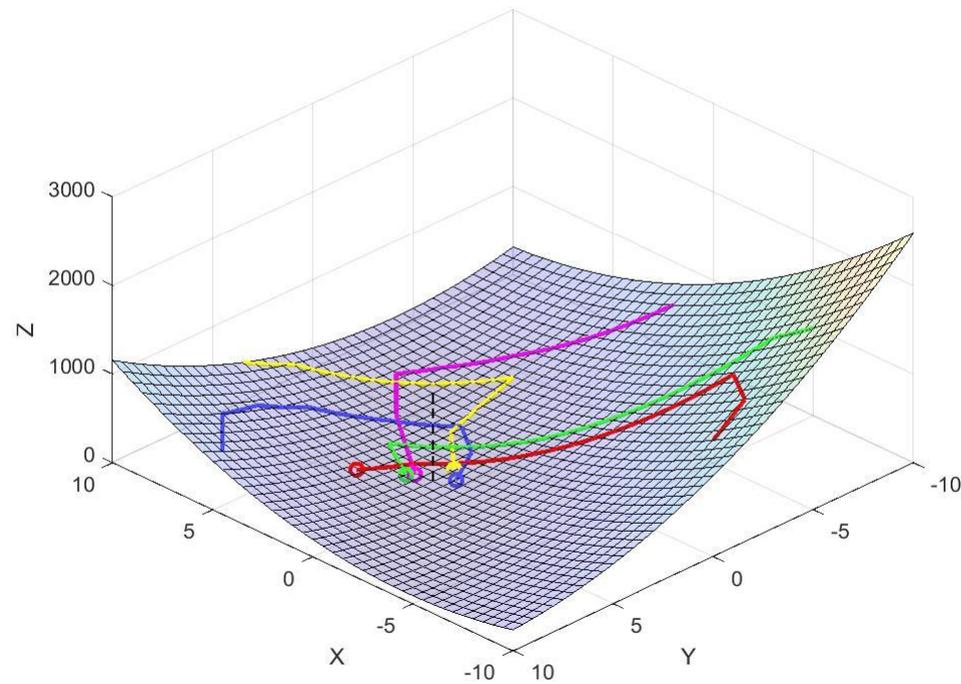
Iteration	Global Best
6	6.1108



Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
7	3.9496

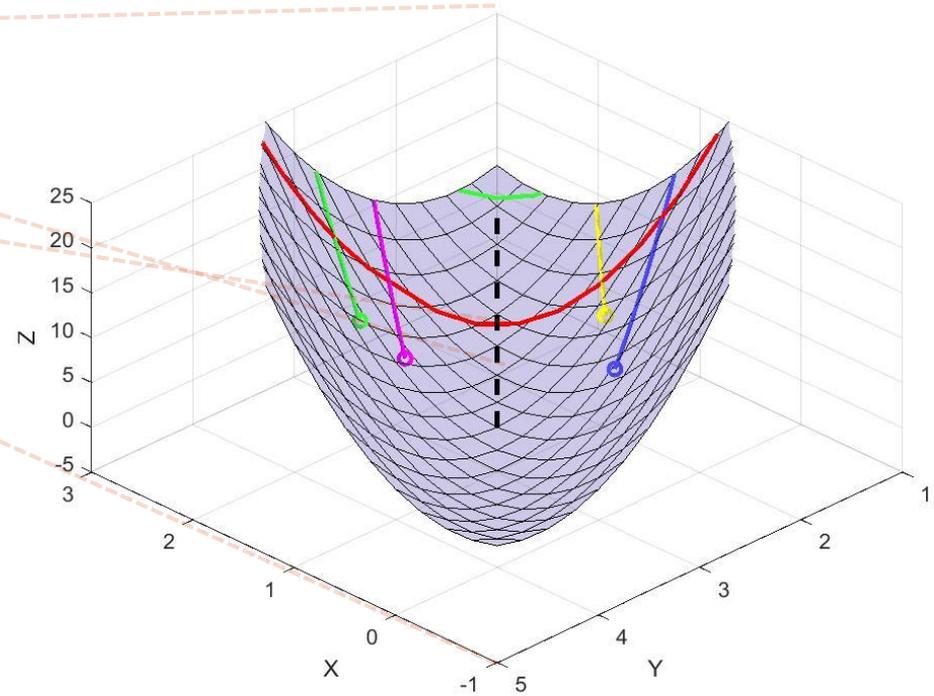
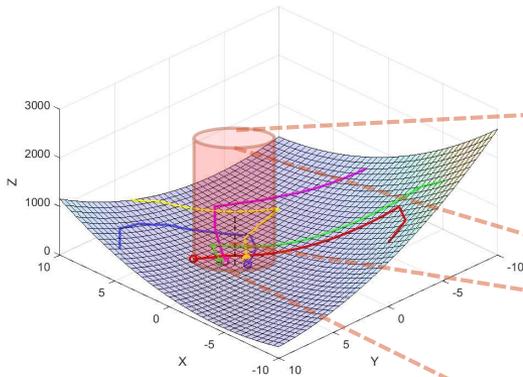




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
7	3.9496

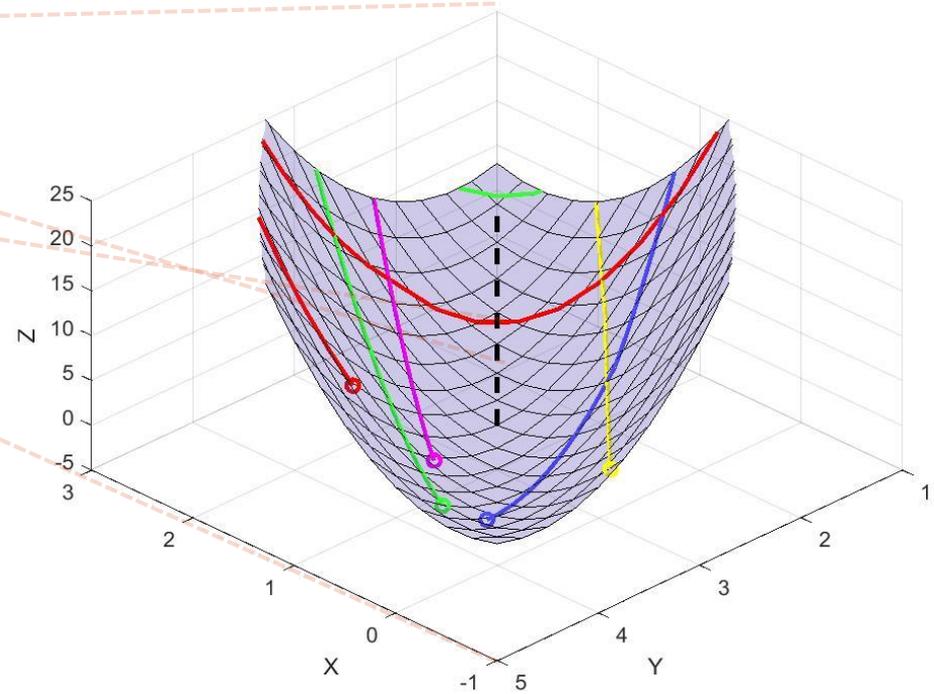
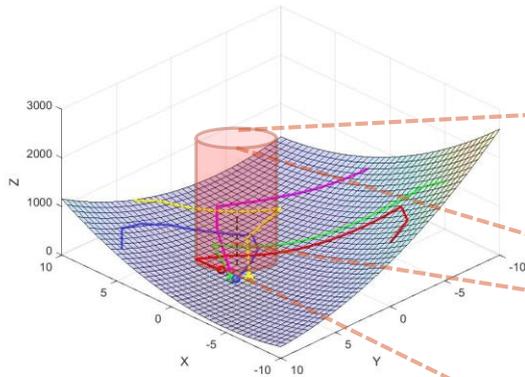




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
8	2.4653

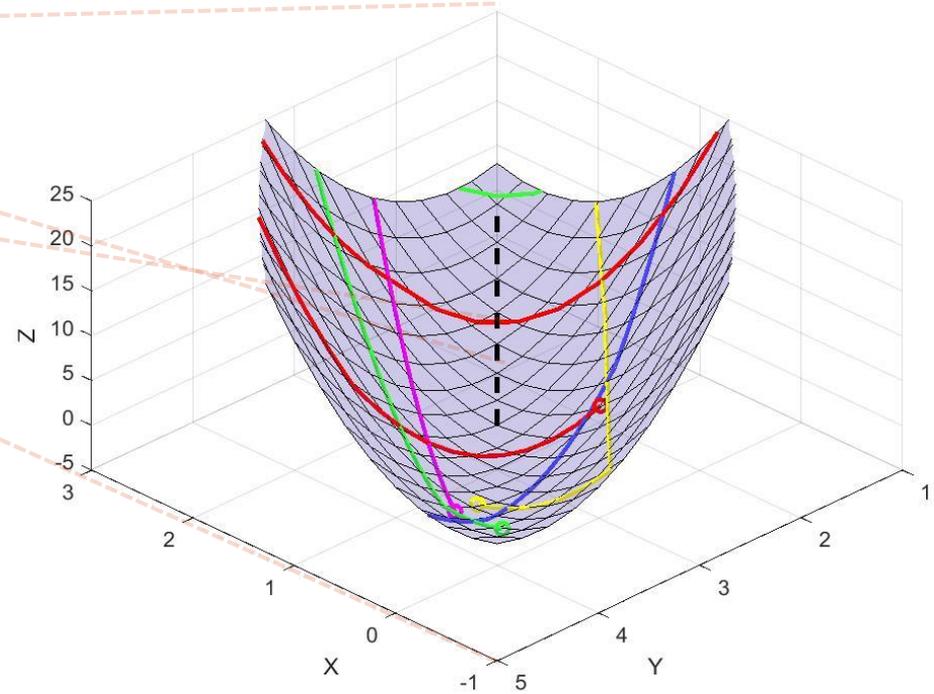
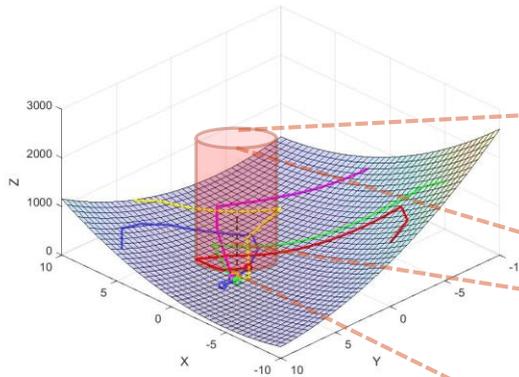




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
9	2.3941

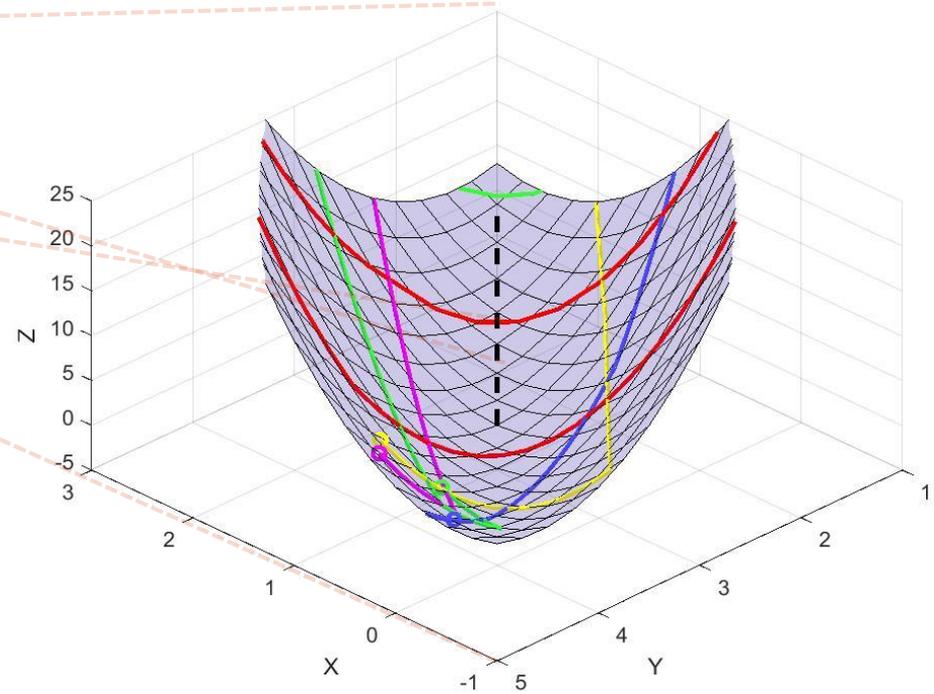
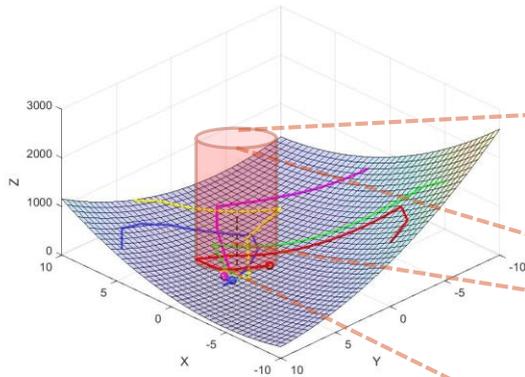




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
10	2.3941

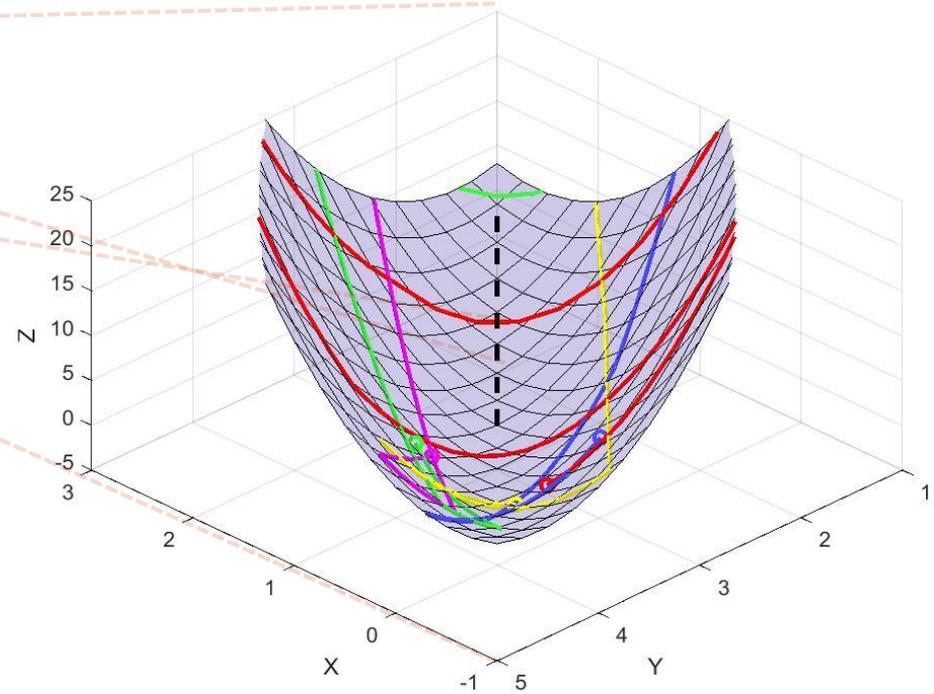
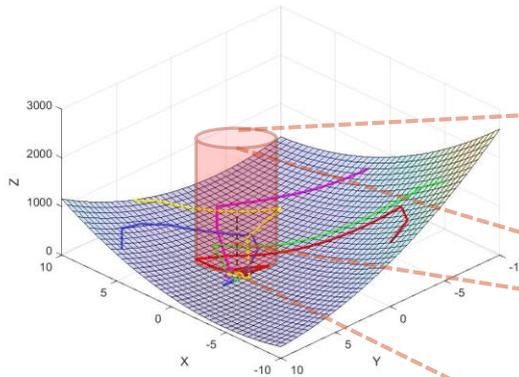




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
11	2.3797

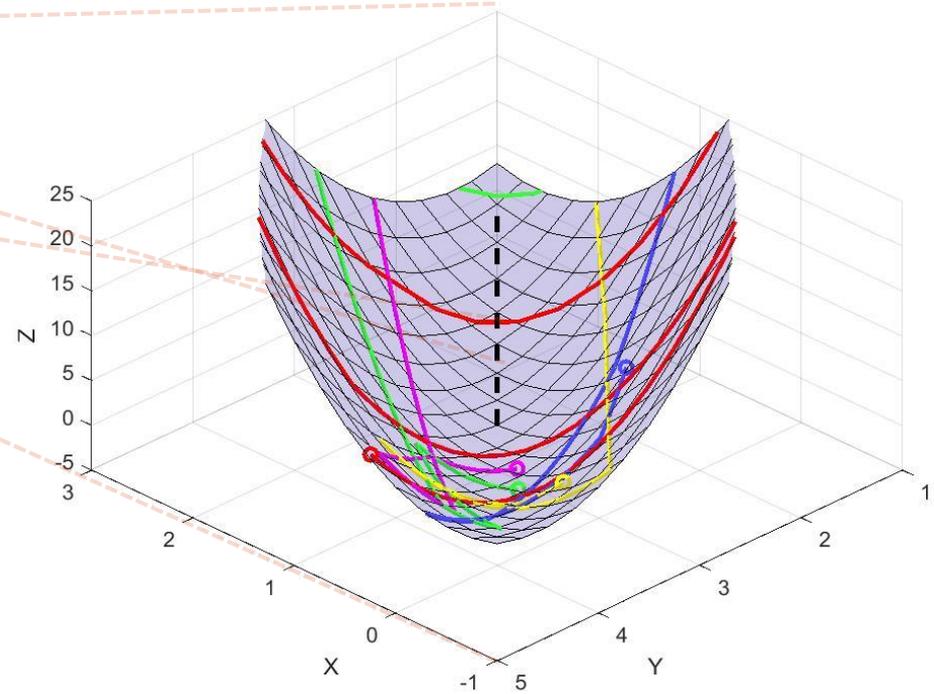
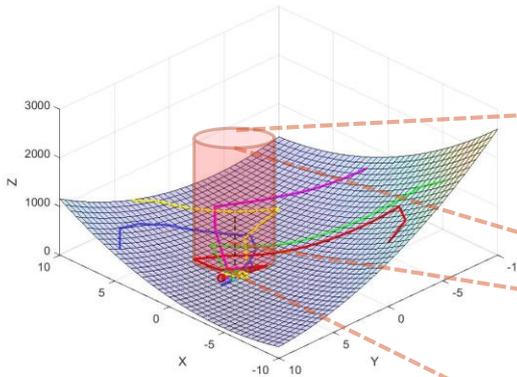




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
12	0.72597

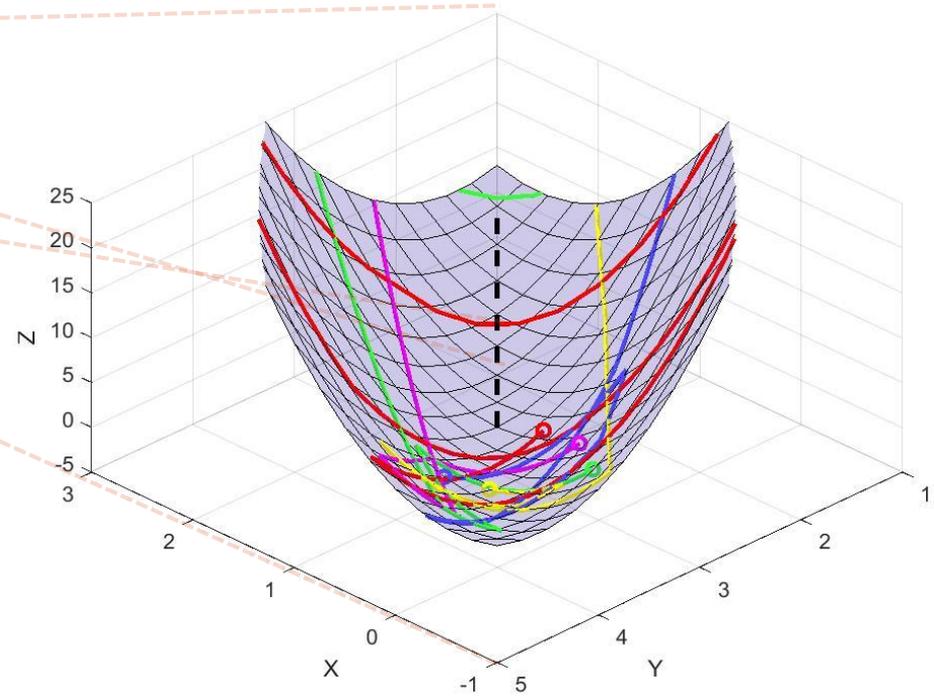
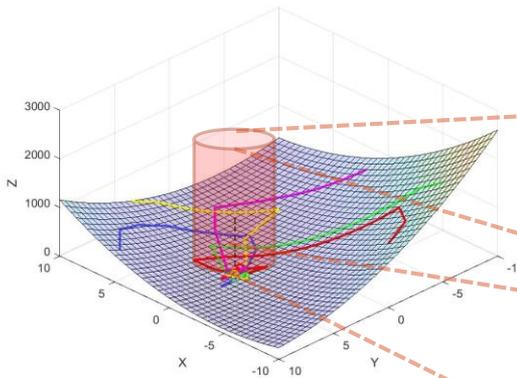




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
13	0.72597

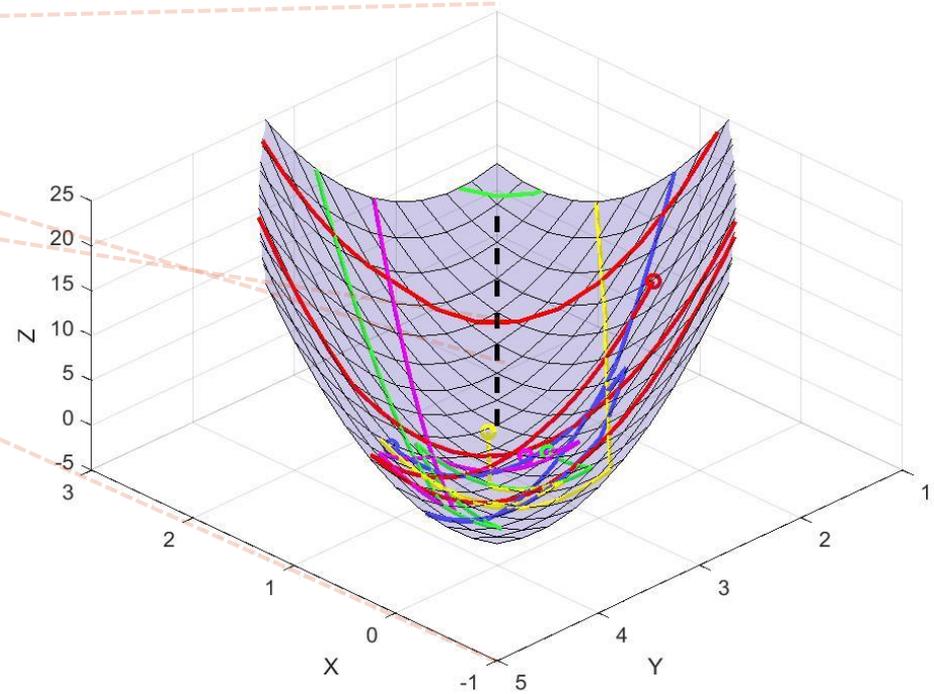
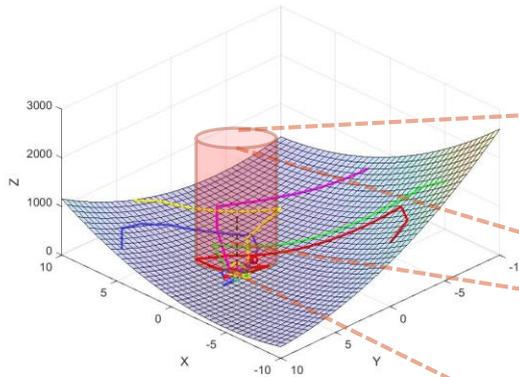




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
14	0.043933

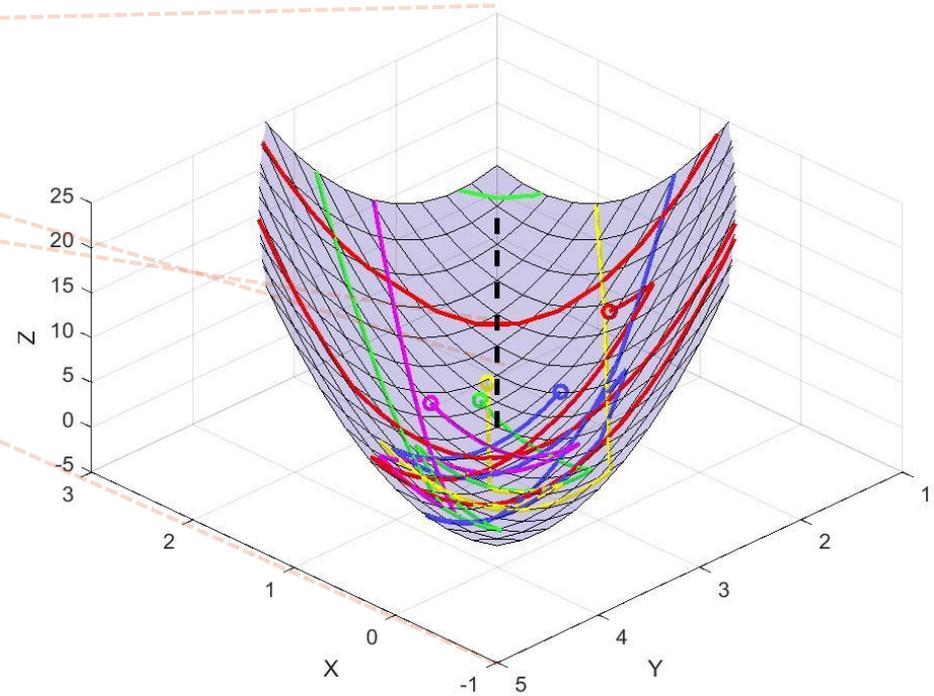
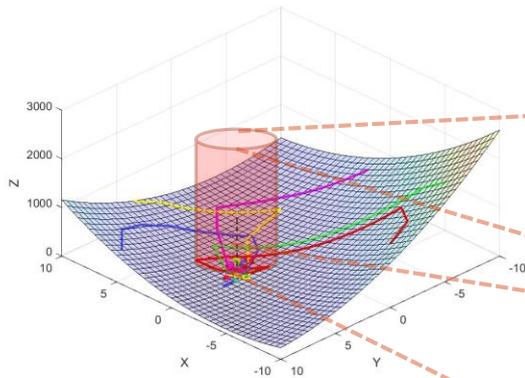




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
15	0.043933

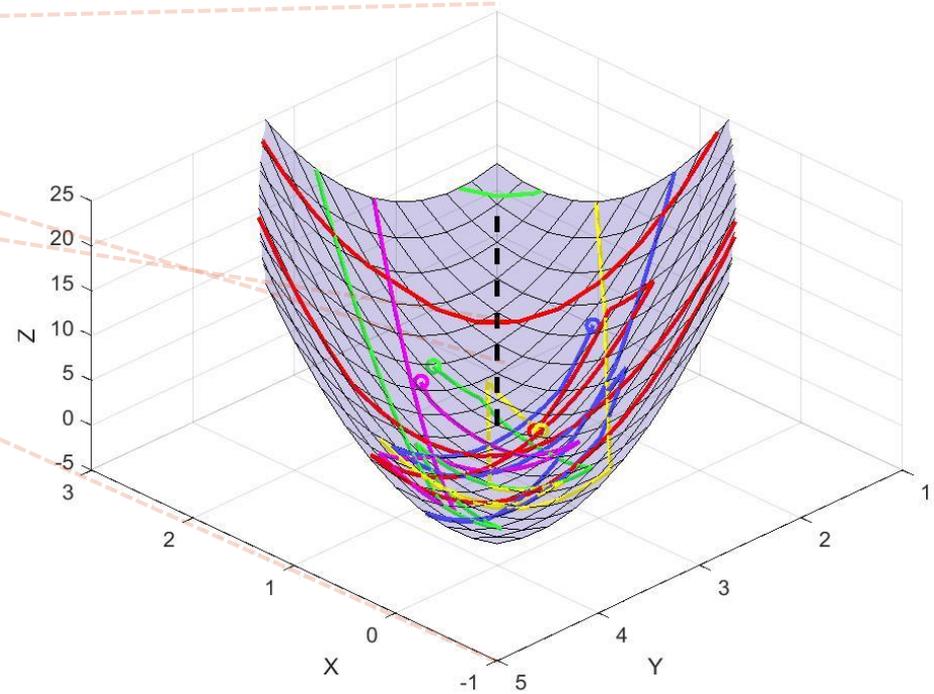
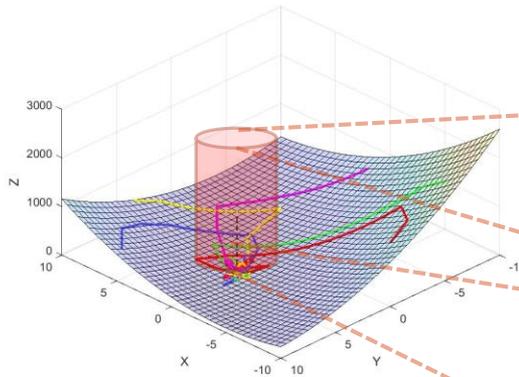




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
16	0.043933

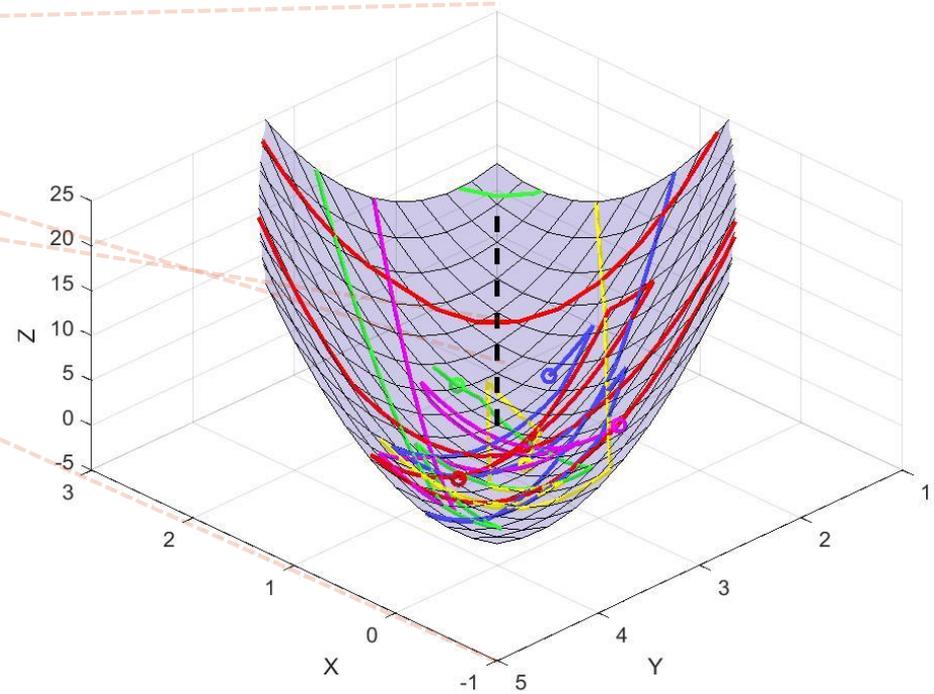
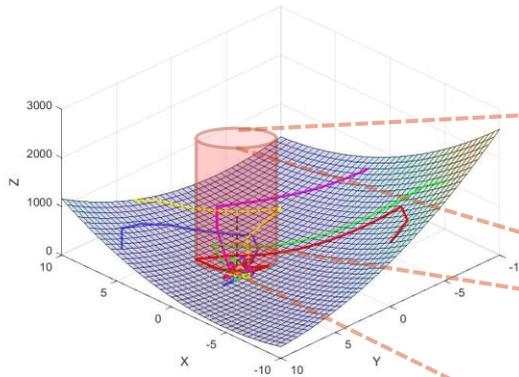




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■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
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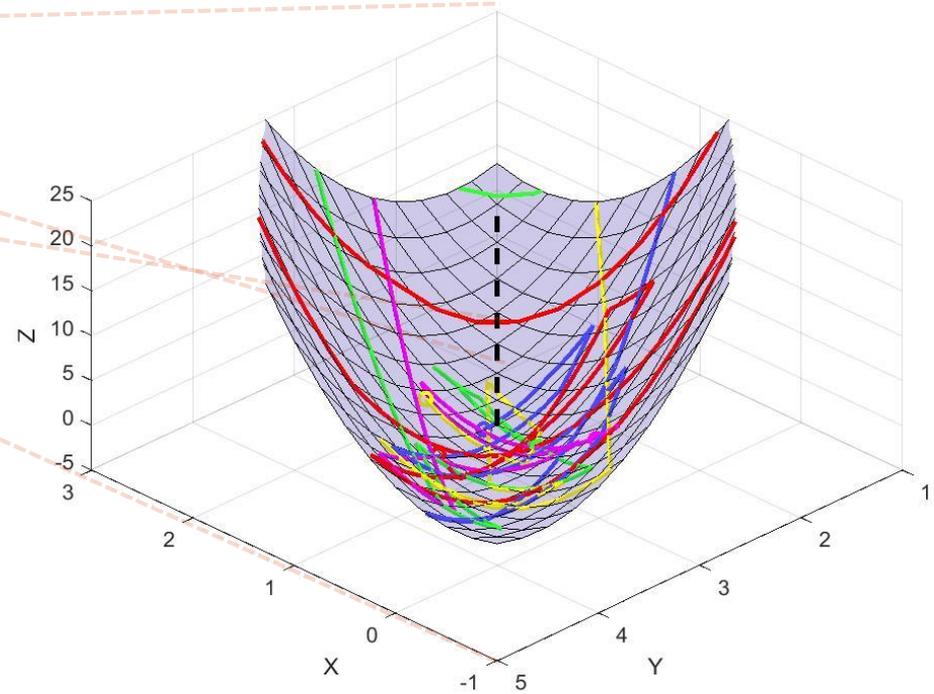
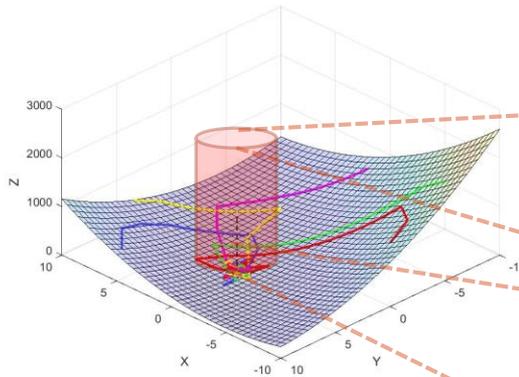




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
18	0.043933

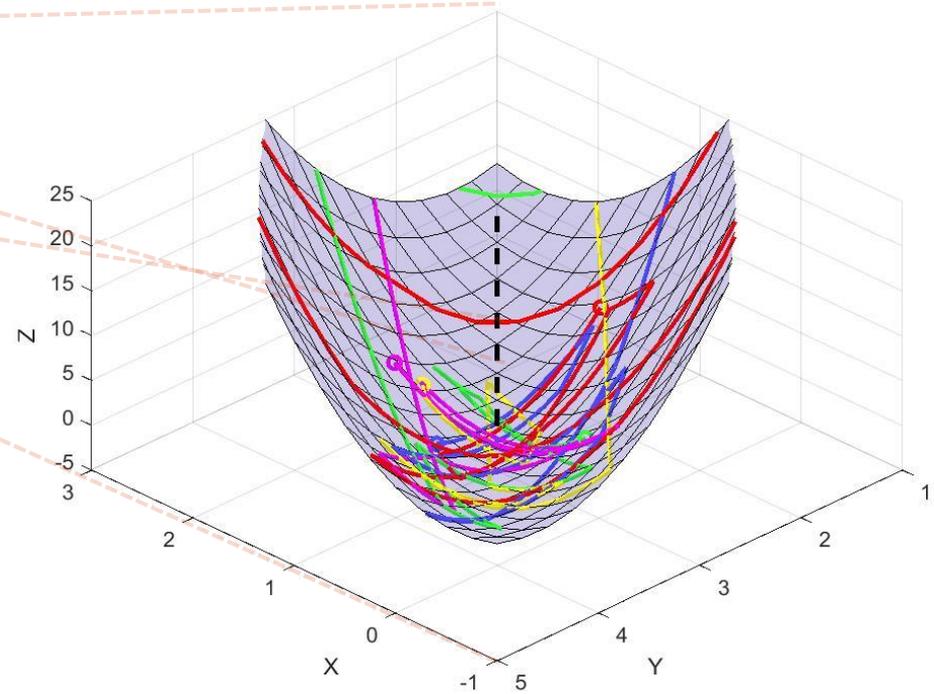
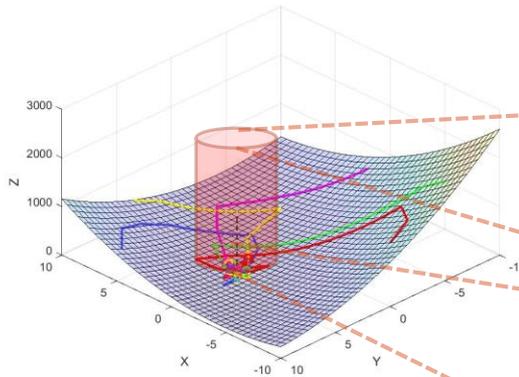




Parallel PSO

■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
19	0.043933

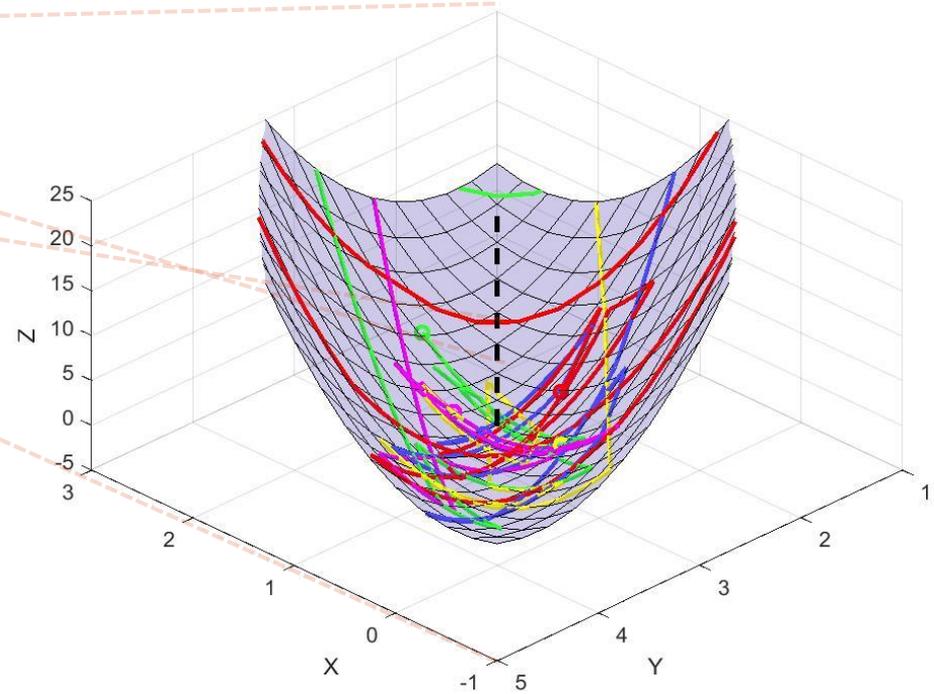
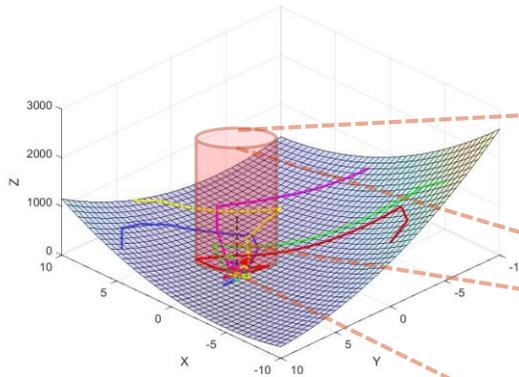




Parallel PSO

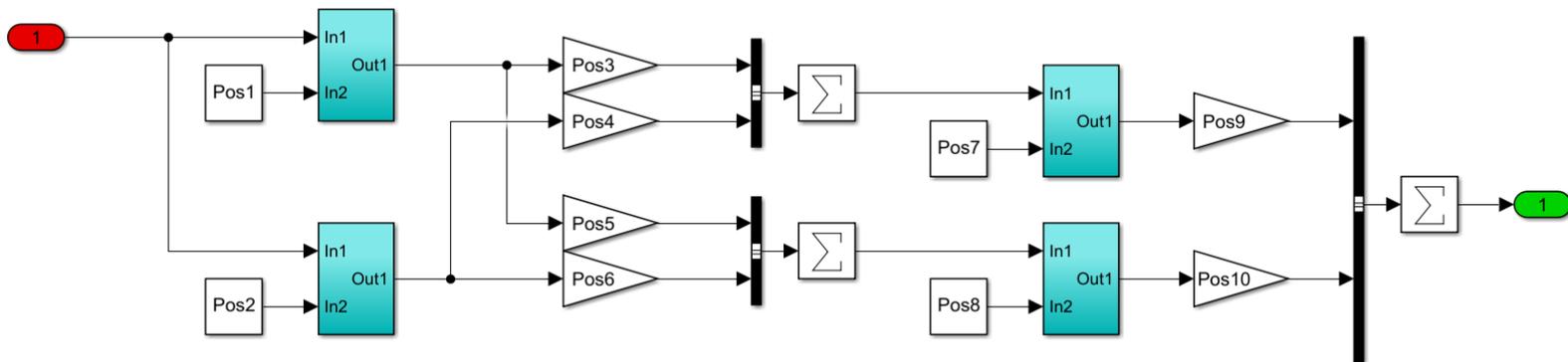
■ $f(x, y) = (x + 2y - 7)^2 + (2x + y - 5)^2$

Iteration	Global Best
20	0.043933



Parallel PSO

- Optimization Examples
 - Feed-forward Neural Network

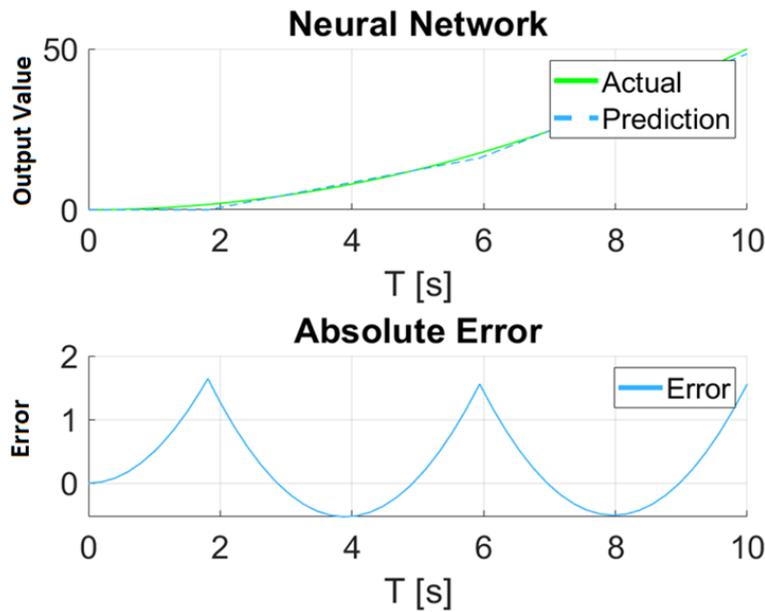


Neural Network Parameters After Optimization

Pos1	Pos2	Pos3	Pos4	Pos5	Pos6	Pos7	Pos8	Pos9	Pos10
1.103	16.17	0.697	2.713	0.854	14.76	0.494	4.129	5.592	4.769

Parallel PSO

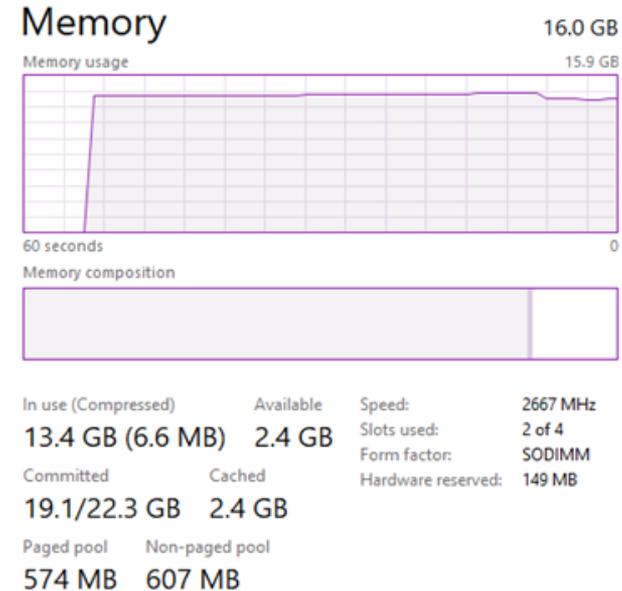
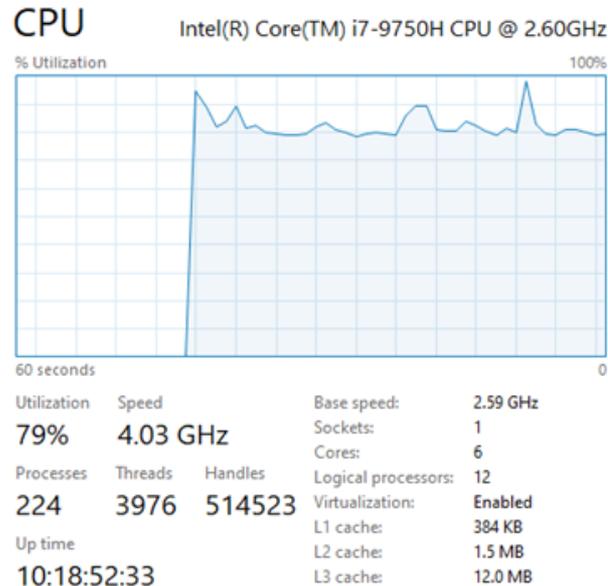
- Optimization Examples
 - Feed-forward Neural Network



$$f(t) = \frac{t^2}{2}$$

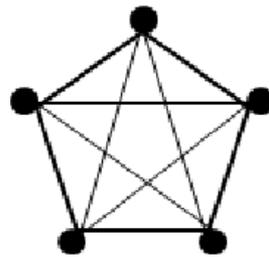
Parallel PSO

- Optimization Examples
 - CPU and Memory Load at Start-up

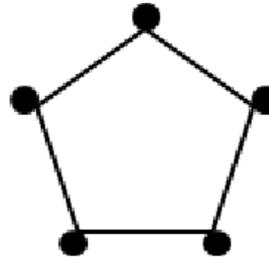


Parallel PSO

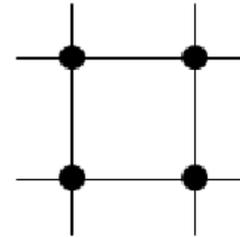
Further Improvement



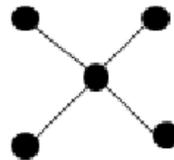
(a) Global



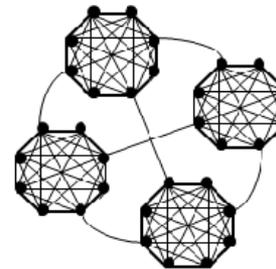
(b) Local



(c) Von Neumann



(d) Wheel

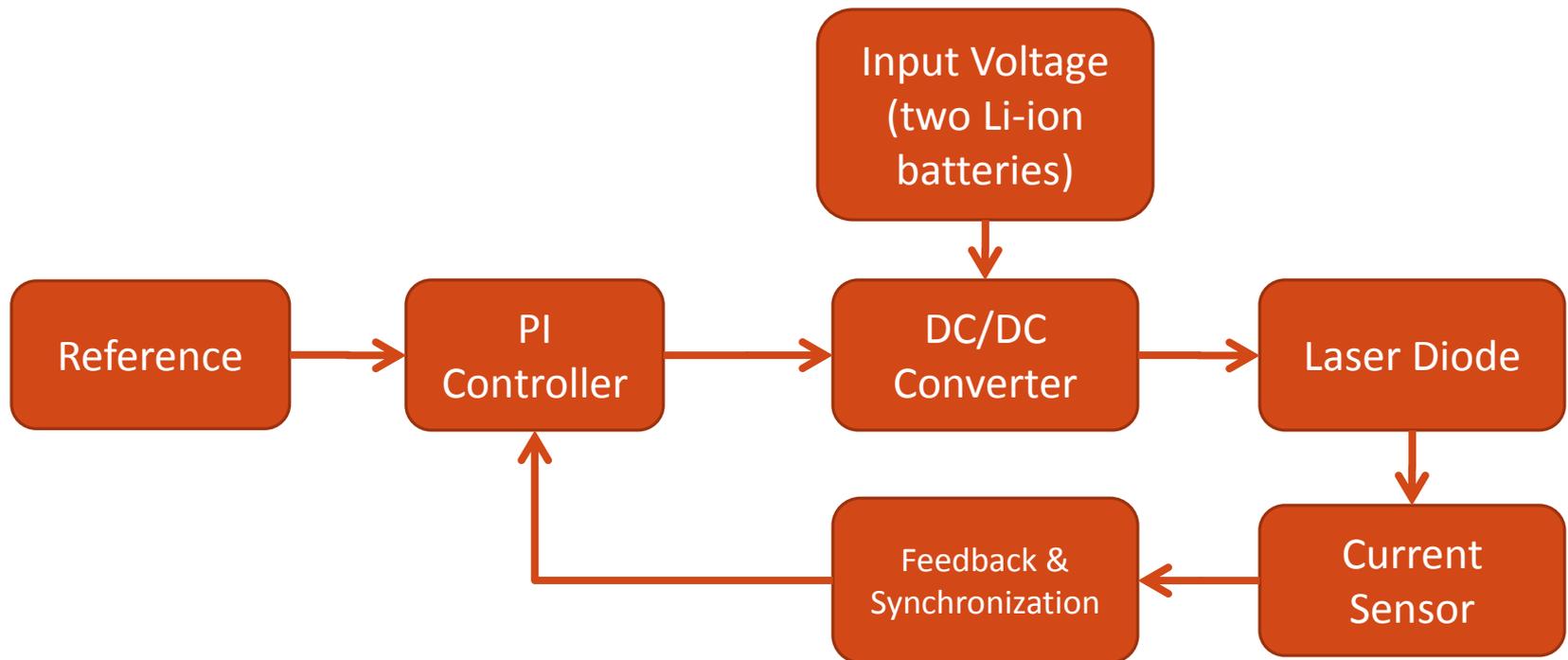


(e) Four Cluster



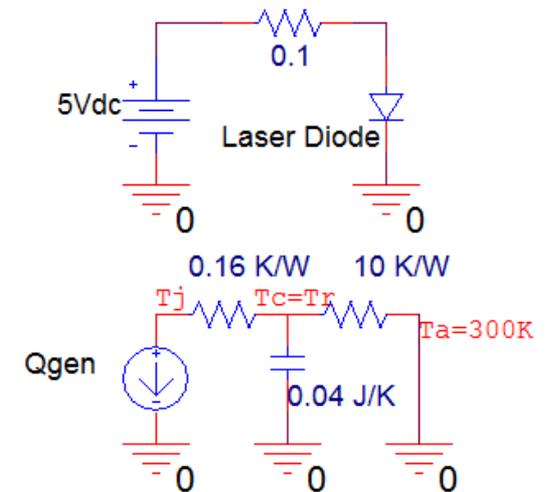
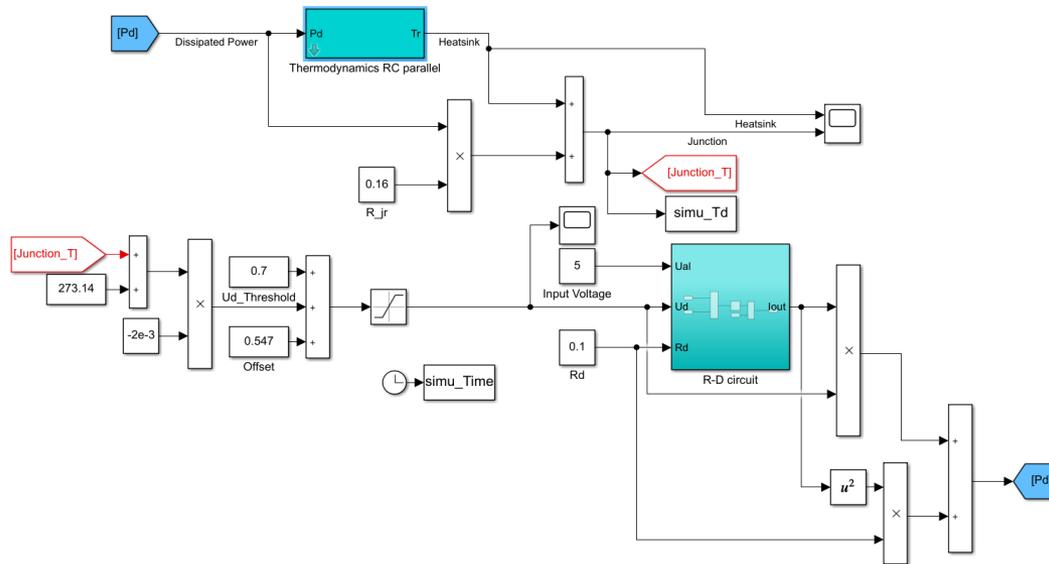
Synchronous Converter

Principles



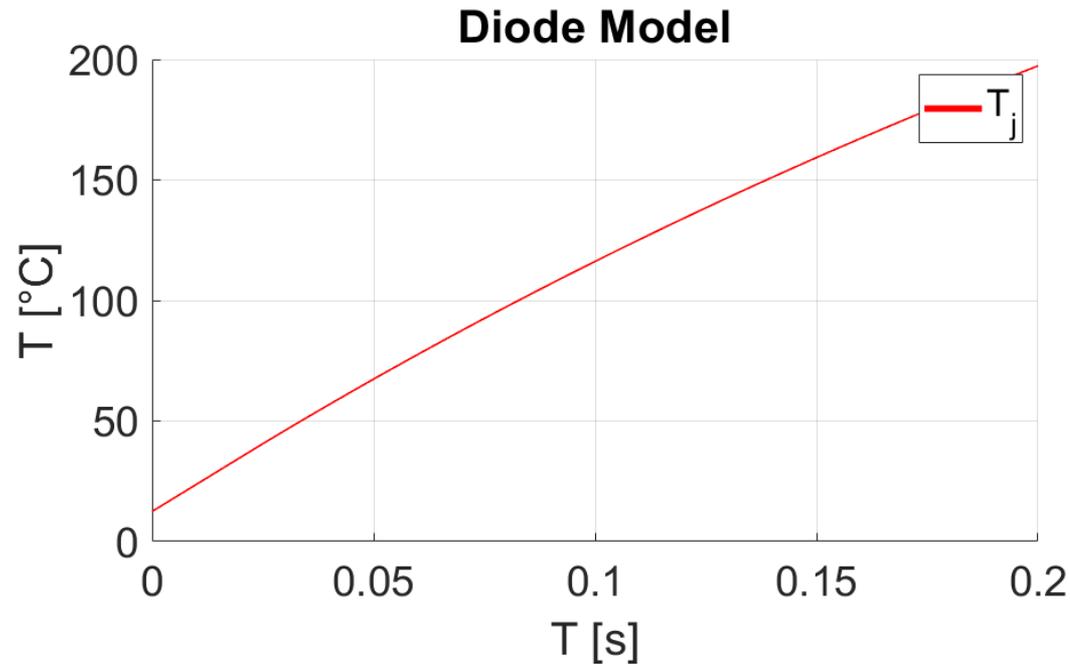
Synchronous Converter

- Simulink Model Description
 - Thermal Runaway



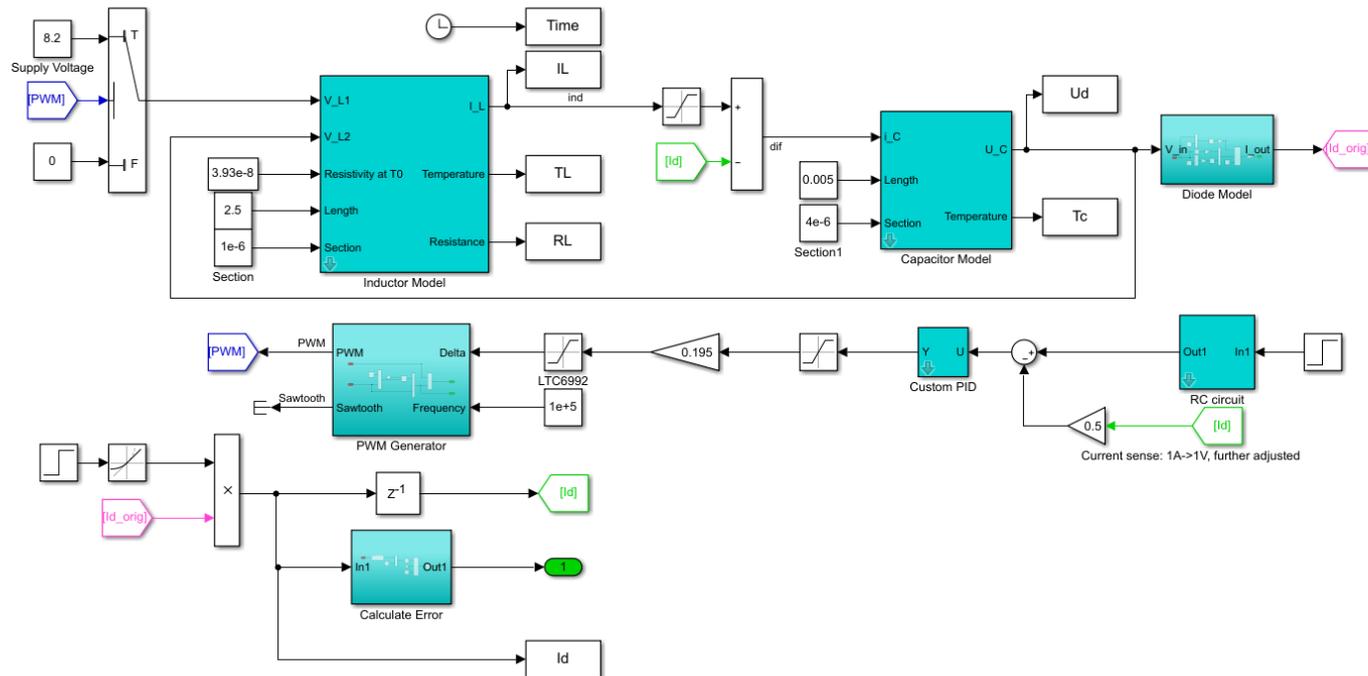
Synchronous Converter

- Simulink Model Description
 - Thermal Runaway



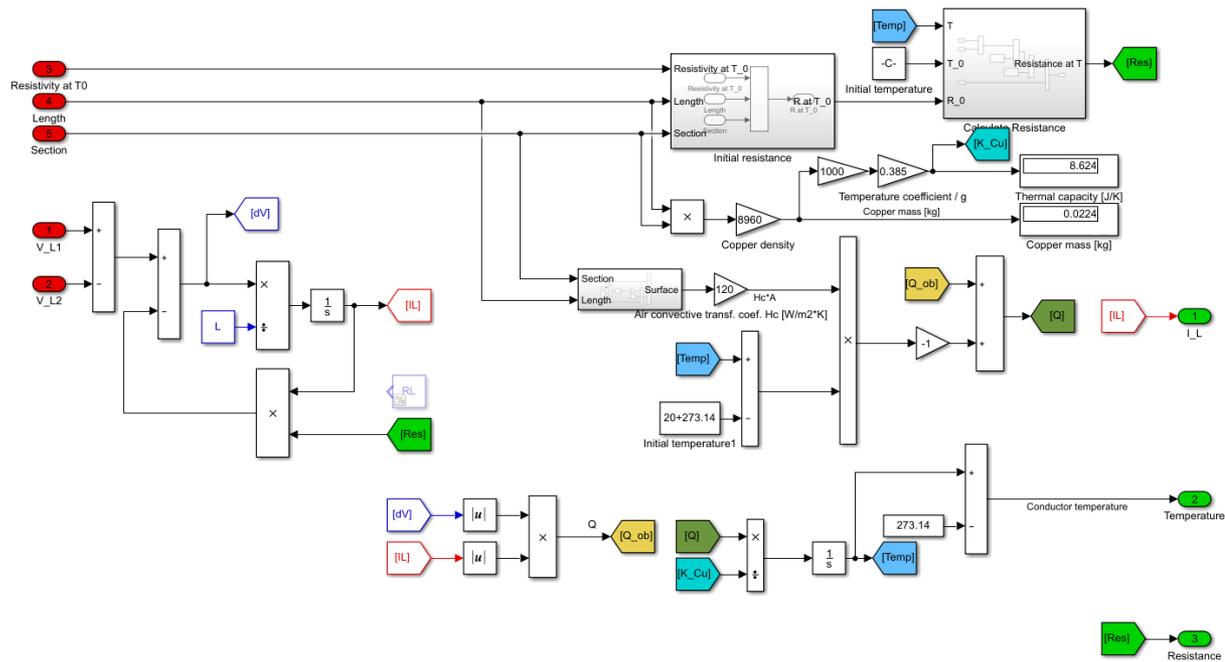
Synchronous Converter

- Simulink Model Description
 - Synchronous Converter



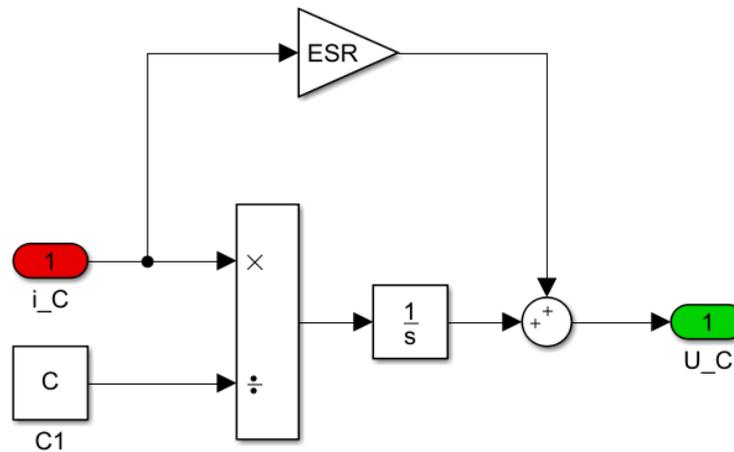
Synchronous Converter

- Simulink Model Description
 - Inductor Model



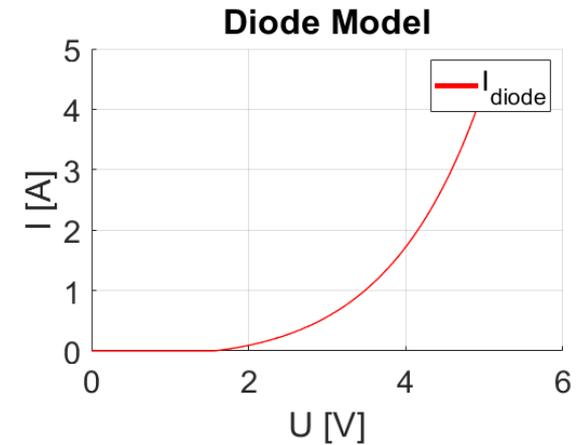
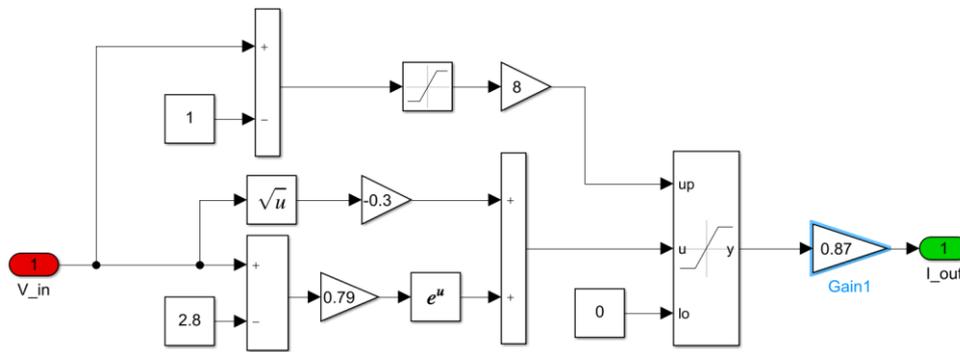
Synchronous Converter

- Simulink Model Description
 - Capacitor Model



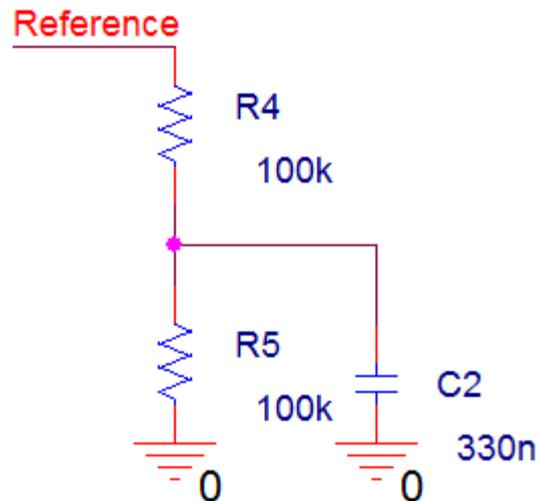
Synchronous Converter

- Simulink Model Description
 - Diode Model



Synchronous Converter

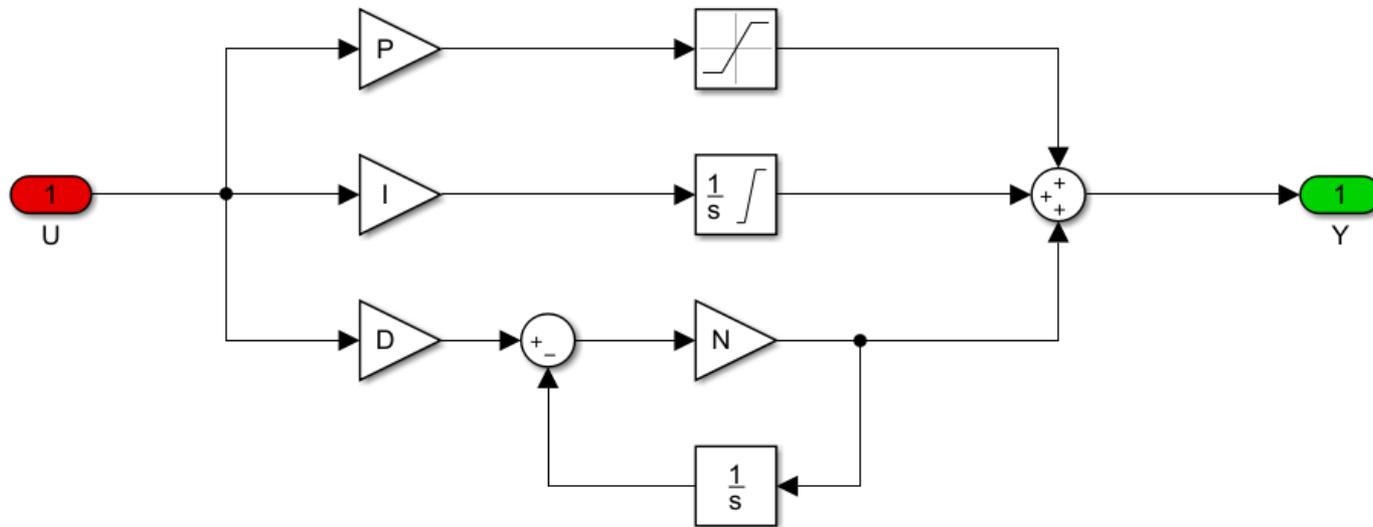
- Simulink Model Description
 - RRC Circuit for Current Reference



$$H(s) = \frac{1}{2 + sRC}$$

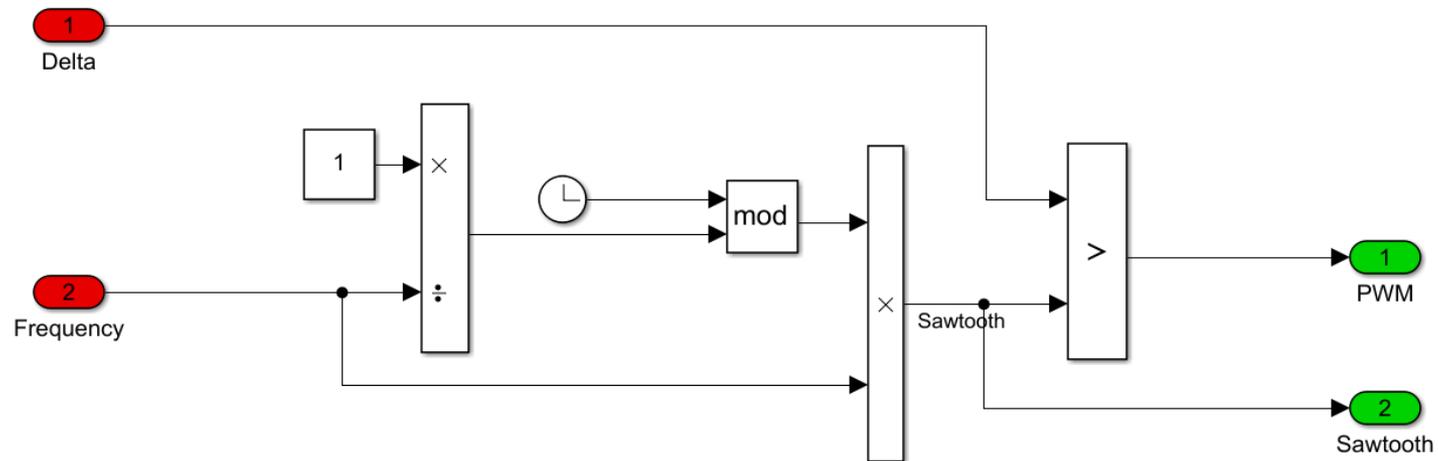
Synchronous Converter

- Simulink Model Description
 - Custom PID Controller



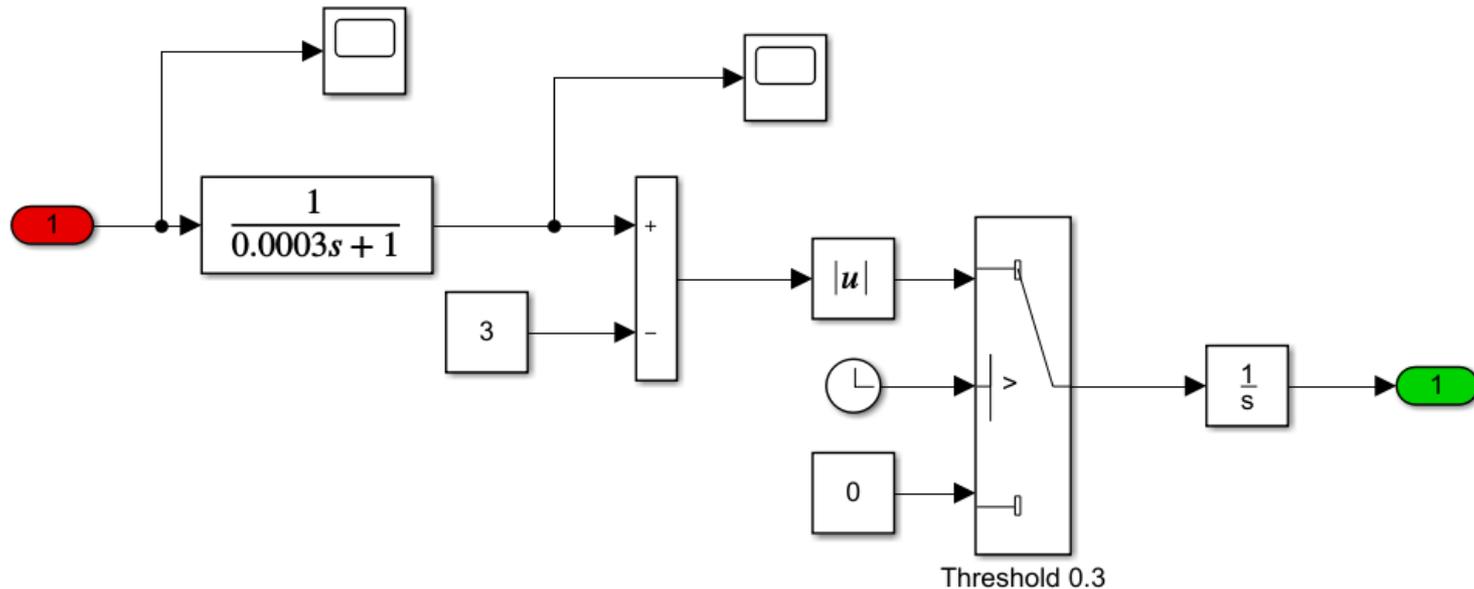
Synchronous Converter

- Simulink Model Description
 - PWM Generator



Synchronous Converter

- Simulink Model Description
 - Error Calculation





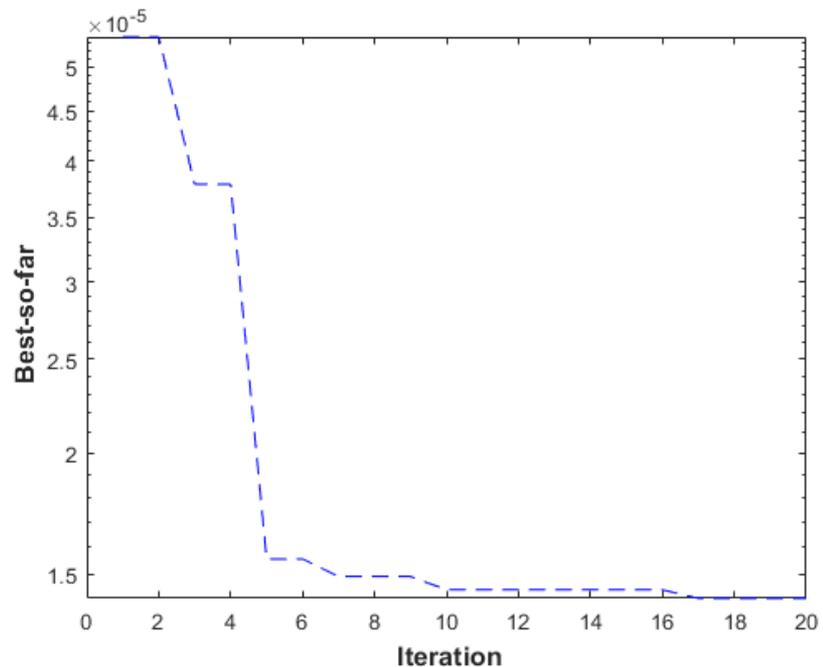
Synchronous Converter

- Simulink Model Description
 - Worst Case Optimization

```
Step=1; E=5.3672e-05; Pos=[106.6528 961.8981]
Step=2; E=5.3672e-05; Pos=[106.6528 961.8981]
Step=3; E=3.7844e-05; Pos=[91.18261 897.7563]
Step=4; E=3.7844e-05; Pos=[91.18261 897.7563]
Step=5; E=1.5556e-05; Pos=[95.84311 909.7809]
Step=6; E=1.5556e-05; Pos=[95.84311 909.7809]
Step=7; E=1.4921e-05; Pos=[96.29387 906.2286]
Step=8; E=1.4921e-05; Pos=[96.29387 906.2286]
Step=9; E=1.4921e-05; Pos=[96.29387 906.2286]
Step=10; E=1.446e-05; Pos=[97.75103 926.2587]
Step=11; E=1.446e-05; Pos=[97.75103 926.2587]
Step=12; E=1.446e-05; Pos=[97.75103 926.2587]
Step=13; E=1.446e-05; Pos=[97.75103 926.2587]
Step=14; E=1.446e-05; Pos=[97.75103 926.2587]
Step=15; E=1.446e-05; Pos=[97.75103 926.2587]
Step=16; E=1.446e-05; Pos=[97.75103 926.2587]
Step=17; E=1.4169e-05; Pos=[98.38147 931.7044]
Step=18; E=1.4169e-05; Pos=[98.38147 931.7044]
Step=19; E=1.4169e-05; Pos=[98.38147 931.7044]
Step=20; E=1.4169e-05; Pos=[98.38147 931.7044]
Elapsed time is 19319.662295 seconds.
```

```
ans =  
1.4169e-05
```

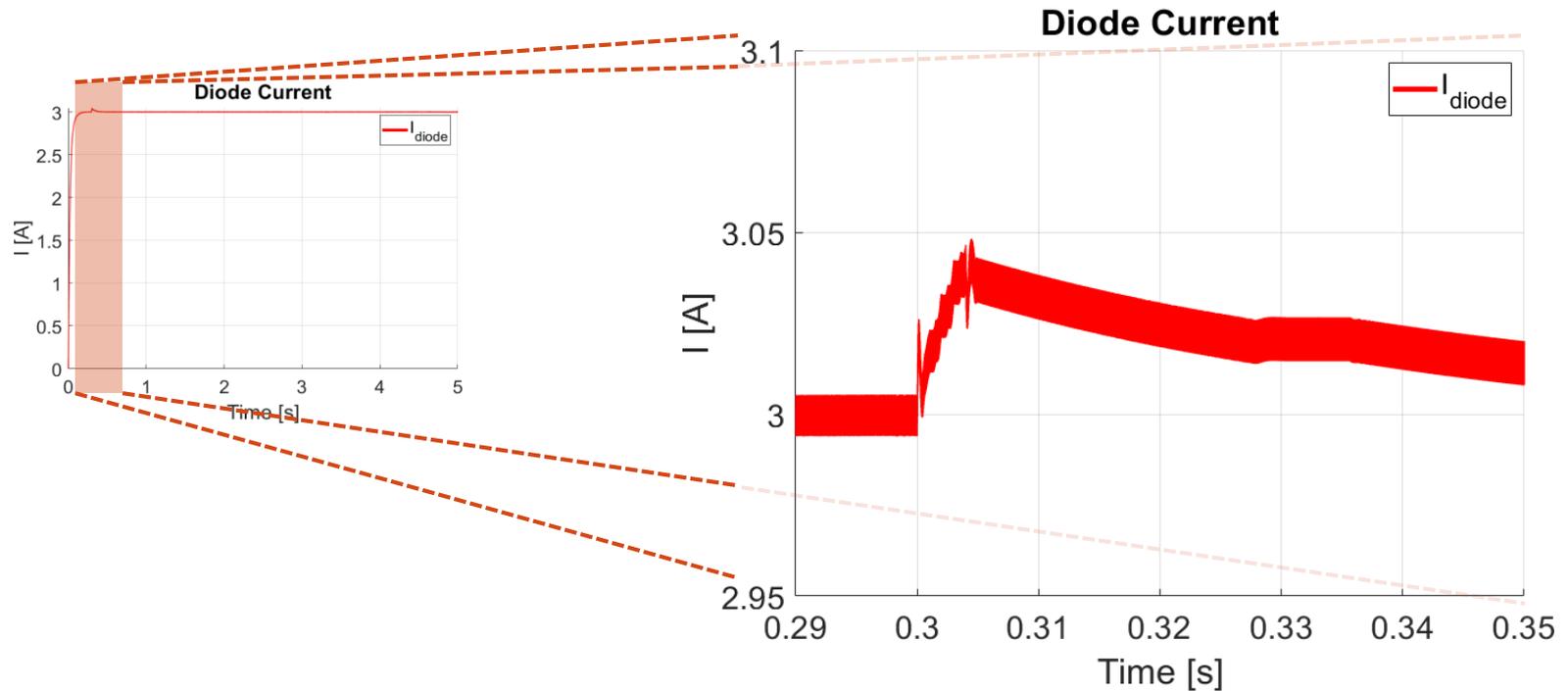
```
f >>
```





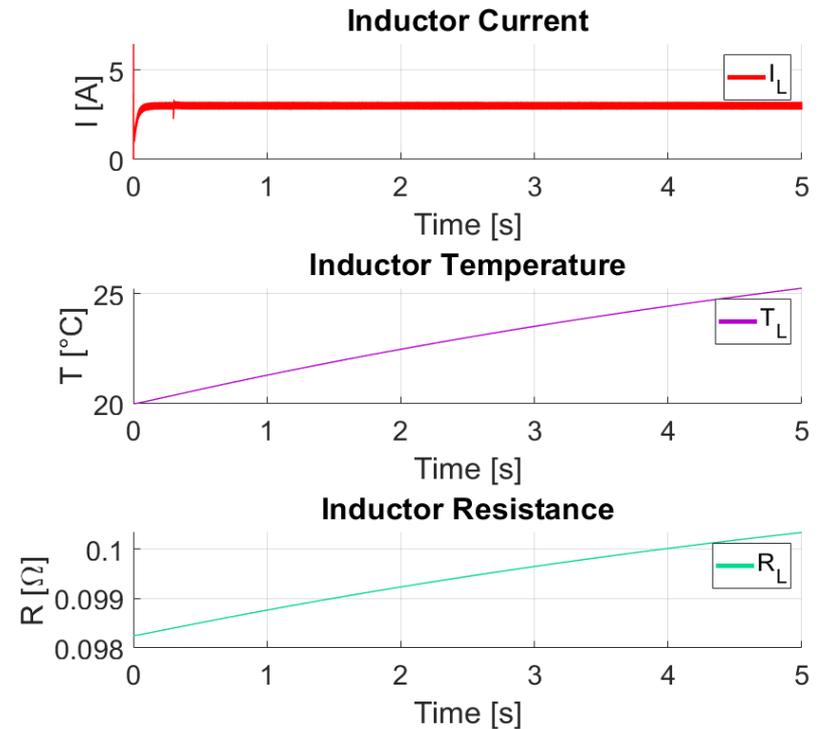
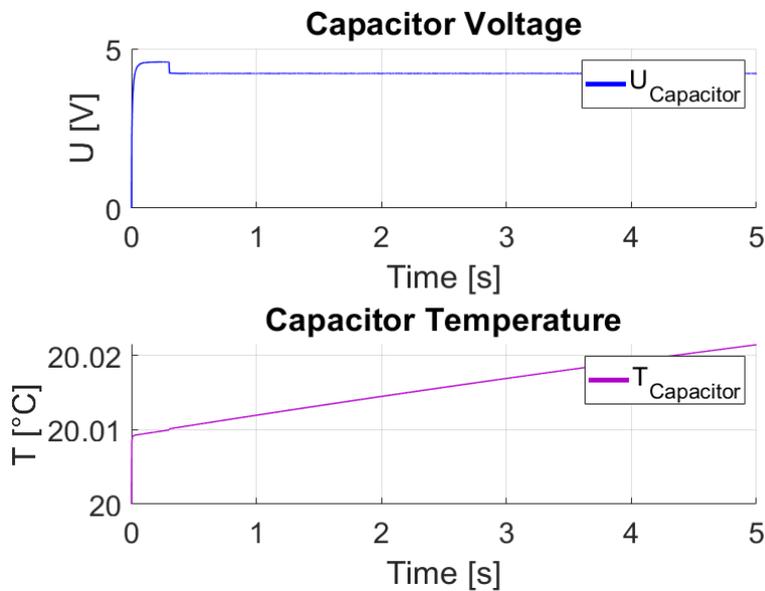
Synchronous Converter

- Simulink Model Description
 - Simulation Result (Worst Case)



Synchronous Converter

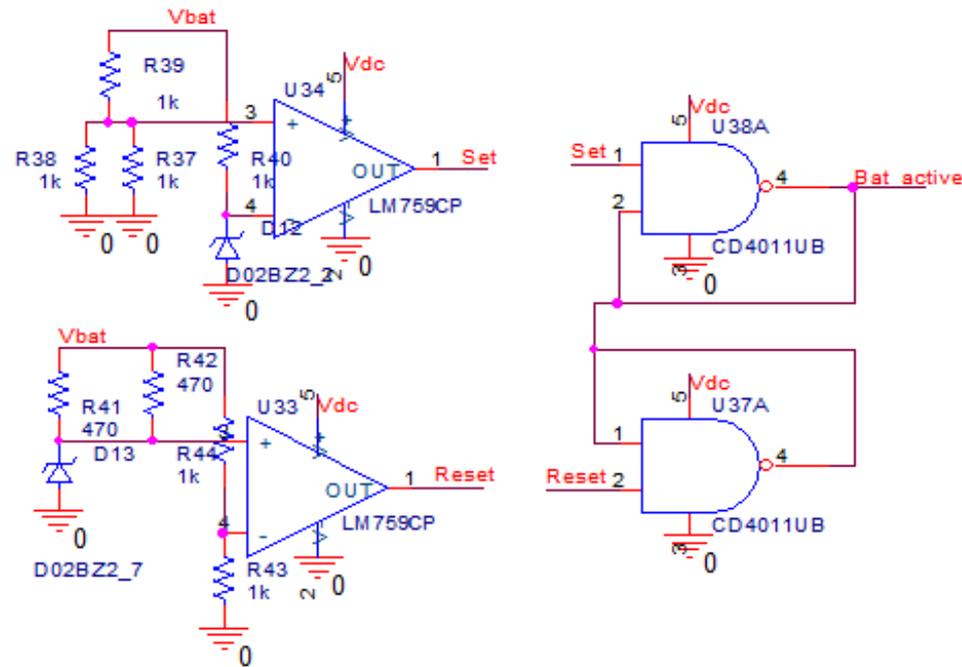
- Simulink Model Description
 - Simulation Result (Worst Case)





Synchronous Converter

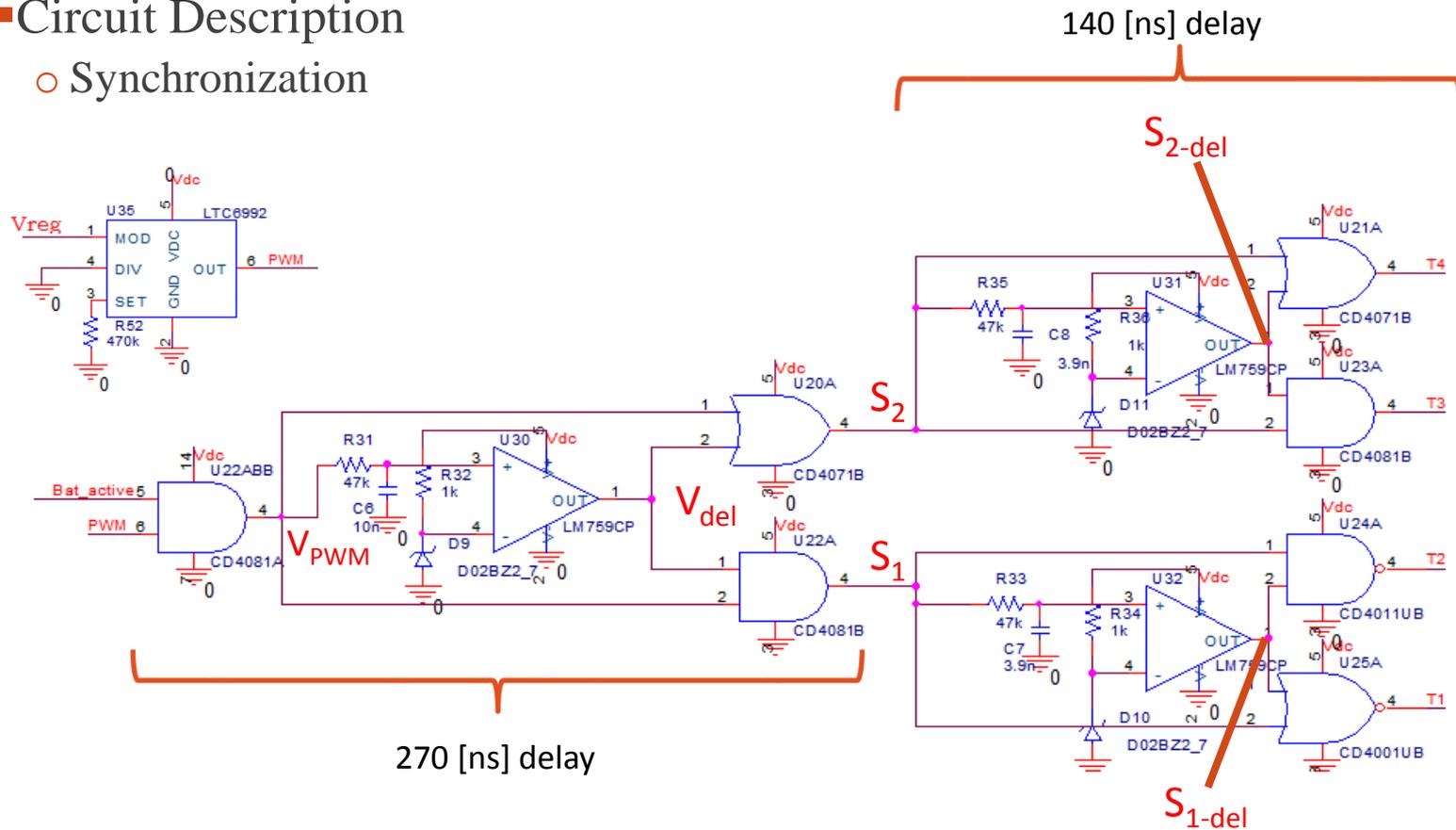
- Circuit Description
 - Low Voltage Shutdown



Synchronous Converter

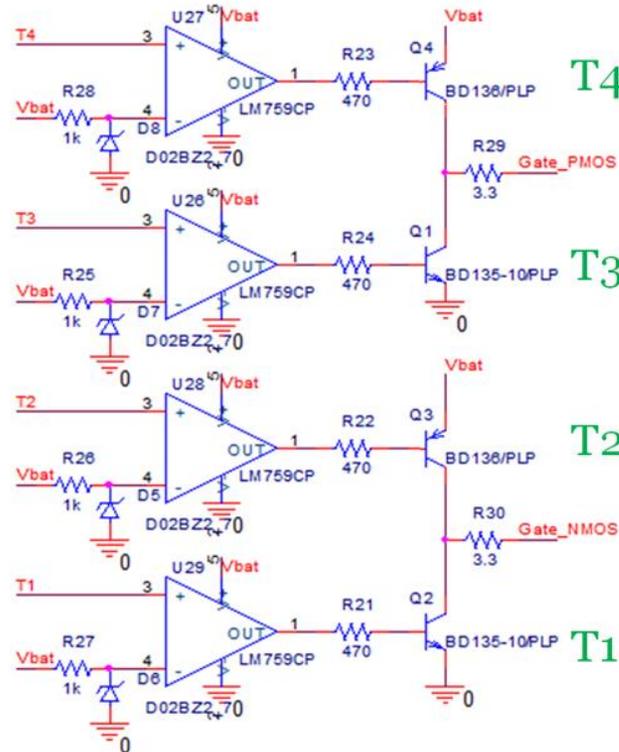
■ Circuit Description

○ Synchronization



Synchronous Converter

- Circuit Description
 - Synchronization





Synchronous Converter

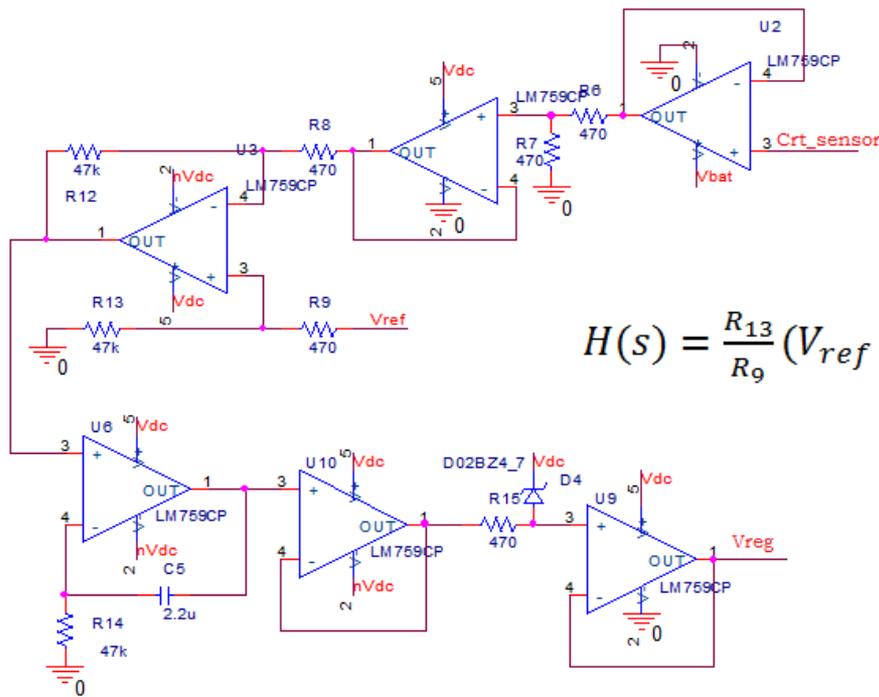
Transition Table

Signals										Device States					
V_{PWM}	V_{del}	S_1	S_{1-del}	T_1	T_2	S_2	S_{2-del}	T_3	T_4	T_1	T_2	T_3	T_4	Q_{PMOS}	Q_{NMOS}
0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	1
0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	1
0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	1
0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	1
1	0	0	0	1	1	1	0	0	1	1	0	0	0	0	1
1	0	0	0	1	1	1	1	1	1	1	0	1	0	0	0
1	1	1	0	0	1	1	1	1	1	0	0	1	0	0	0
1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0
1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0
1	1	1	1	0	0	1	1	1	1	0	1	1	0	1	0
0	1	0	1	0	1	1	1	1	1	0	0	1	0	1	0
0	1	0	0	1	1	1	1	1	1	1	0	1	0	0	0
0	0	0	0	1	1	0	1	0	1	1	0	0	0	0	0
0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	1

Synchronous Converter

■ Circuit Description

○ Regulator



$$R_8 = R_9$$

$$R_{12} = R_{13}$$

$$H(s) = \frac{R_{13}}{R_9} (V_{ref} - V_{sense}) + \frac{R_{13}}{R_9} \cdot \frac{1}{R_{14}C_5} \int (V_{ref} - V_{sense}) dt$$

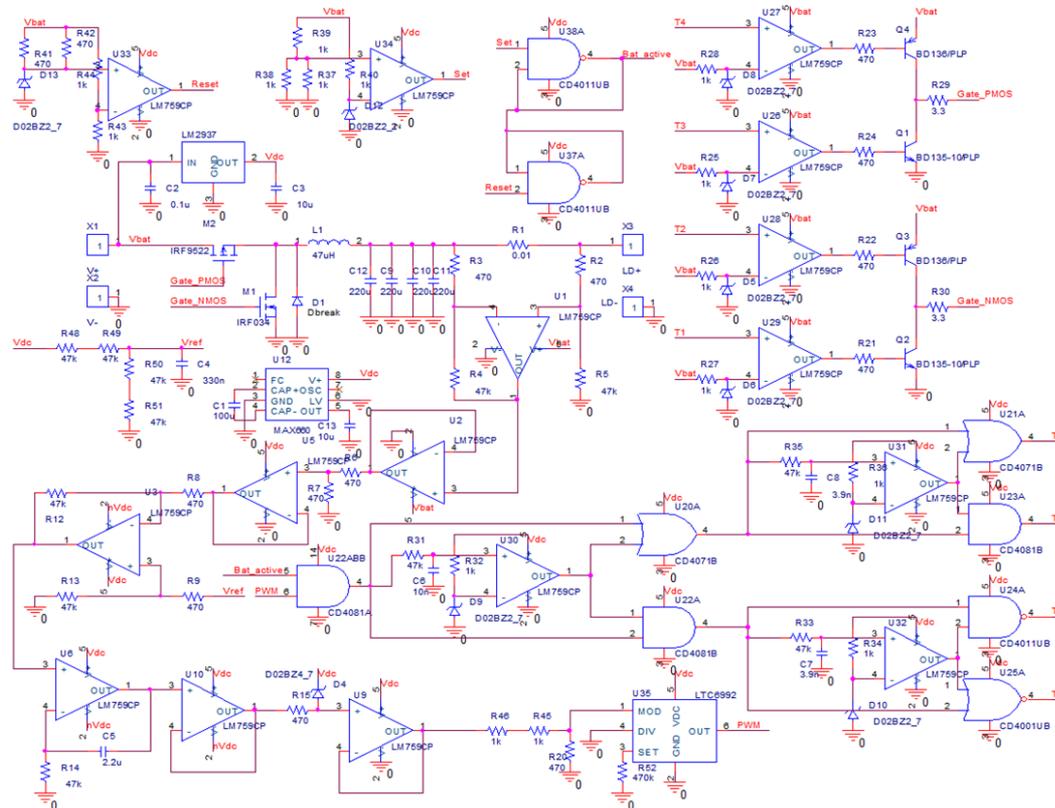


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Synchronous Converter

Complete Circuit





Synchronous Converter

■ PCB Footprint for Components

Part	Footprint
Capacitors	SM/C_0805
LC Filter Capacitors	SM/C_1210
Inductor	SM/R_2520
Schottky Diode	TO252AB/DPAK
Zener Diodes	SM/C_0805
MOSFET, LM2937	SM/SOT223
BJT	SM/SOT23
Resistors	SM/C_0805
Current Sense Resistor	SM/C_1210
Operational Amplifiers	SM/SOT23_5



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Synchronous Converter

- Equivalent Laboratory Laser Power Test
 - <https://youtu.be/touMJ5KI1fU>



Conclusions

1. SMD laser driver prototype

2. Closed-loop current controller design

3. Parallel PSO validation

4. Mathematical model optimization

5. Converter output parameters validation



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Thank you for your attention!