

Lab(6) PID Controller Design

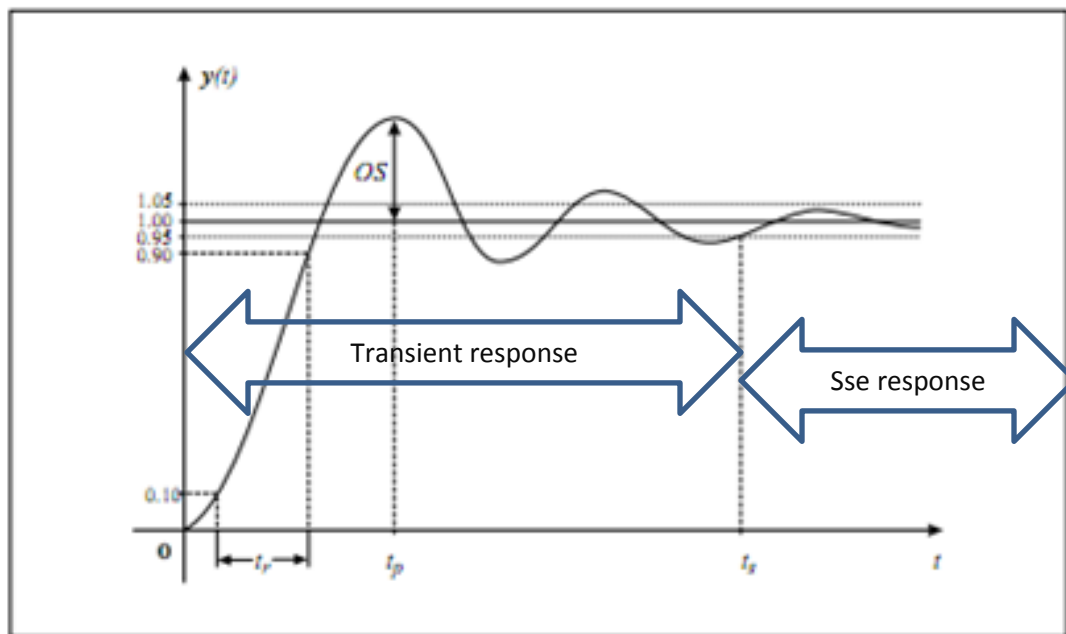
In this lab we will learn how to design a controller using root locus but before this we need to answer the following questions:

- What is root locus?
- What is the purpose of the controller?
- What is the relation between close loop system poles and the response?
- What are the types of controller?
- How to select the right controller for the system?

To answer the first question root locus is a graphical presentation of the close loop poles movement on the axes as the gain k change from zero to infinity.

To answer the second question the purpose of the controller is to adjust the system to meet the required specification as settling time, over shoot, peak time, and sse.

Before answering the third question we need to know that the response has two part the transient part and the steady state part



Response of an under-damped second-order system

When talking about transient response we talk about settling time, rise time and overshoot and when talking about ss response we talk about ss error. Remembering the second order transfer function formulas we have

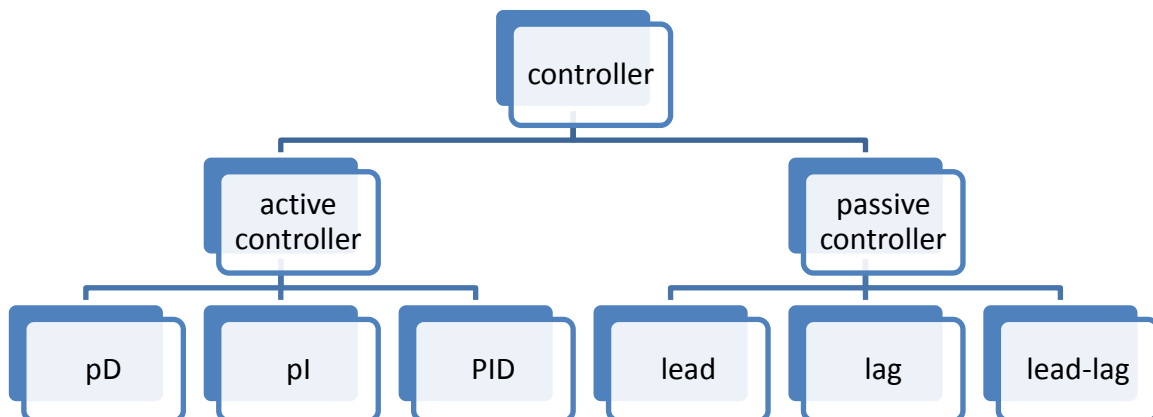
$$g(s) = \frac{w_n^2}{s^2 + 2\zeta w_n s + w_n^2} \quad s_{1,2} = -\zeta w_n \pm jw_n \sqrt{1 - \zeta^2}$$

$$Ts = \frac{4}{\zeta w_n} \quad Os = e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}}$$

$$Tp = \frac{\pi}{\omega_n \sqrt{1 - \zeta^2}}$$

Since the overshoot depends on (damping ratio ζ) and the settling time and peak time depend on (damping ratio ζ and the damping frequency w_n) and since the poles formula consist of damping ratio and damping frequency then changing the poles will change the damping ratio and damping frequency which will result in a change in transient response and ss response

To answer the fourth question, there are many types of controller and can be divided in two categories the first is the passive controller and second is the active controller



The difference between the two categories is that the active controller is more accurate since it is implemented using computer and microprocessors and the passive controller is inaccurate compared to active since it is implemented using resistor and capacitors but one advantage for the passive controller over active controller is the price.

Before answering consider this, if the controller changes the system response parameter like settling time, rise time, overshoot, and steady state error, then the controller will have to change the poles' location to another location which satisfies the required specification and the question here is this location is on the root locus or not on the root locus?

If the location is in the root locus, then the required specifications can be achieved by using (P controller) only and if the location is not on the root locus, then we need to add zero (PD controller) for example in order to change the root locus to pass through that location.

Another method to choose the right controller is to see where the required specification lies. For example, if we need to change the transient response, use PD controller, and if we need to change the steady state response, we need PI controller.

Controller name	Controller transfer function	effects
Proportional	$C(s)=k$	All (ss + transient)
Proportional + derivative (PD)	$C(s)=k(s+z)$	Transient and small effect on ss
Proportional + integral (PI)	$\frac{k(s+z)}{s}$	ss and small effect on transient
Proportional + integral derivative (PID)	$\frac{k(s+z_1)(s+z_2)}{s}$	All

What is the difference between proportional and PID

Controller design using Matlab:-

There is a main tool in Matlab used to design a controller using root locus and its name is sisotool

The sisotool gives you many things

- 1- System root locus
- 2- System bode plot
- 3- Close loop and open loop systems step responses
- 4- The formula of the controller and the required gain

In order to use the sisotool write sisotool (sys) and sys can be state space of TF or ZPK

Example :-

Design a PD controller for the following system to get a damping ration of 0.707 and settling time of 2 sec

$$g(s) = \frac{1}{s(s+2)(s+5)}$$

Step 1 :-

we need to find the desire close loop location

$$Ts = \frac{4}{\zeta w_n} = 2$$

$$2\zeta w_n = 4 \rightarrow w_n = \frac{4}{2 * 0.707} = \boxed{2.82}$$

$$s_{1,2} = s_{1,2} = -\zeta w_n \pm jw_n \sqrt{1 - \zeta^2} = \boxed{-2 \pm 2j}$$

Step 2 :-

We need to enter the system on Matlab and activate the sisotool

```
Num=[1]
Den=[1 7 10 0]
Sys=tf(num,den)
Sisotool(sys)
```

A siso tool consists of the following two figures:

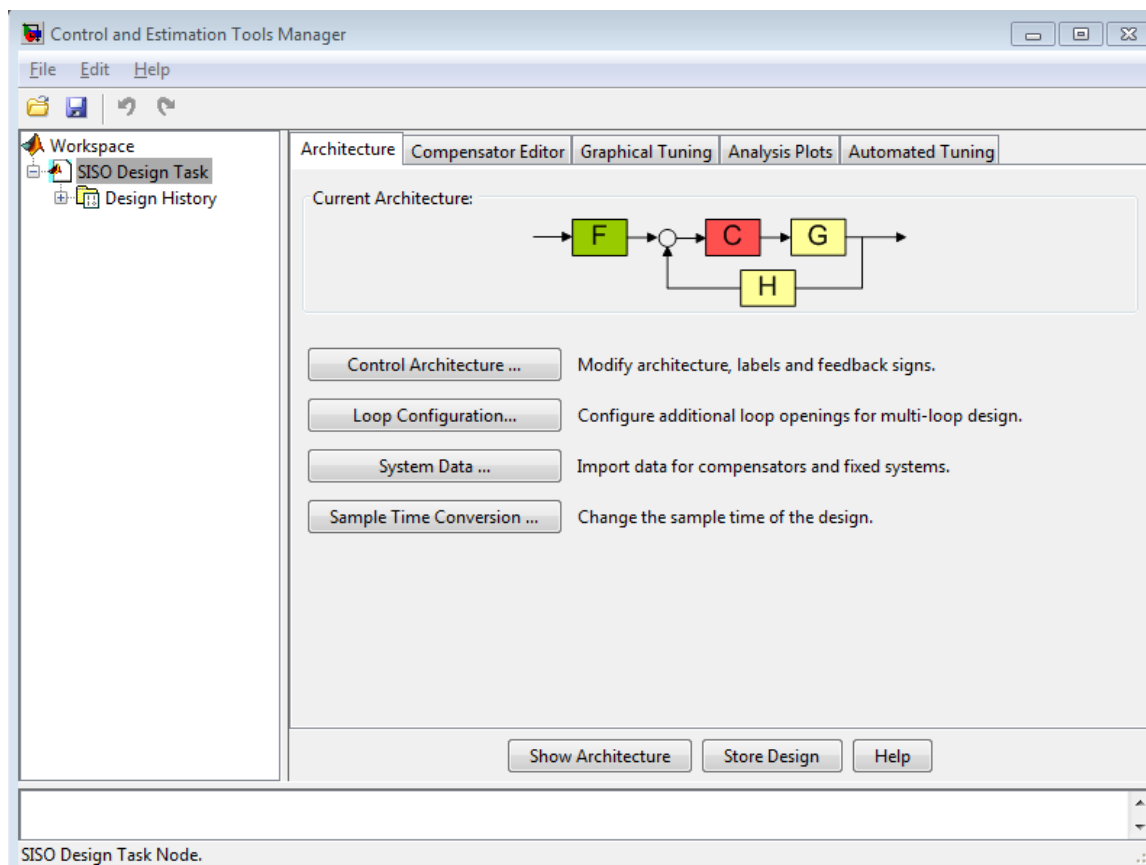
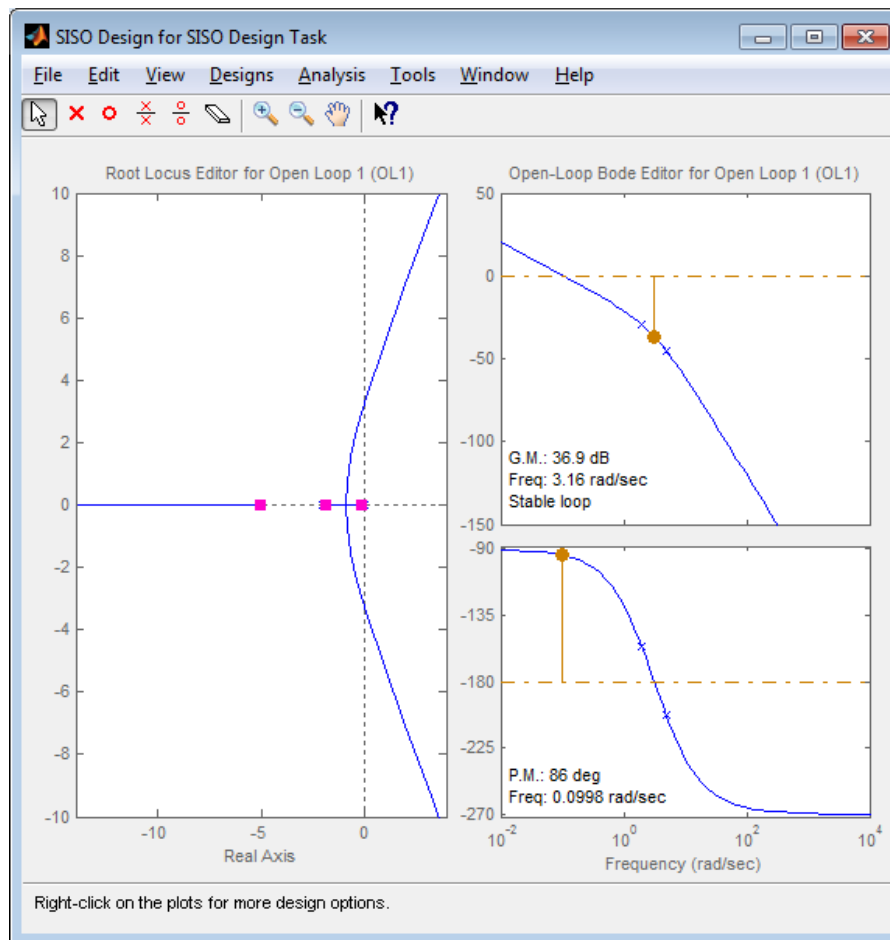


Figure 1 sisotool first figure



Step 3:-

we need to locate the desire point ($-2 \pm 2j$) on the sisotool.

To place a pair of complex poles on your diagram at a damping ratio of 0.707, select

Design requirement and then **New**, the following menu will appear

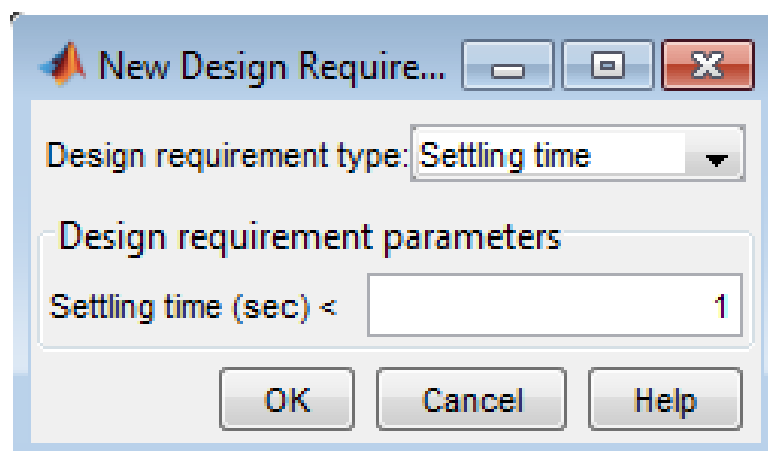


Figure 3 design requirement menu

Form this menu insert the settling time value which equal s 2 and the following change will appear on the siso tool

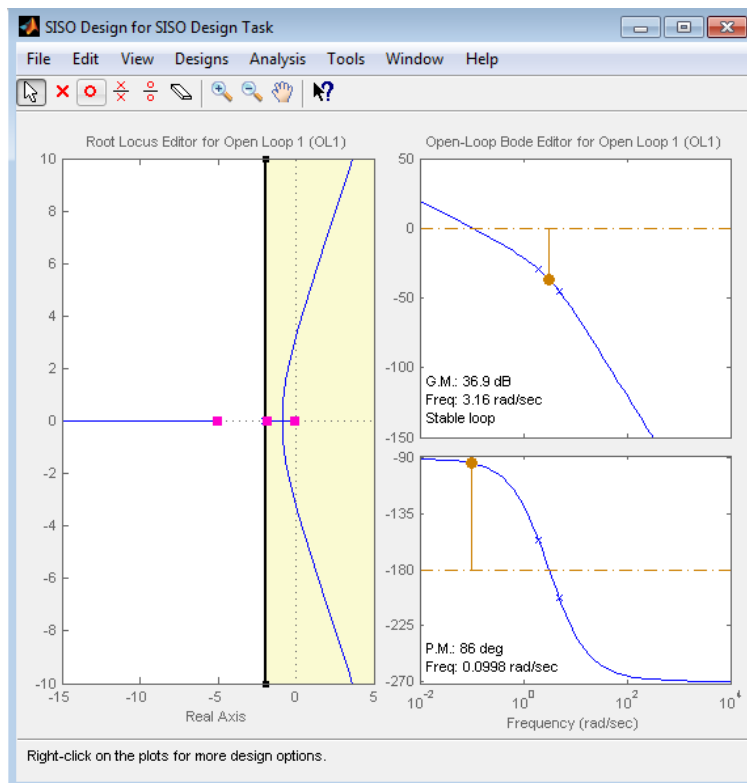
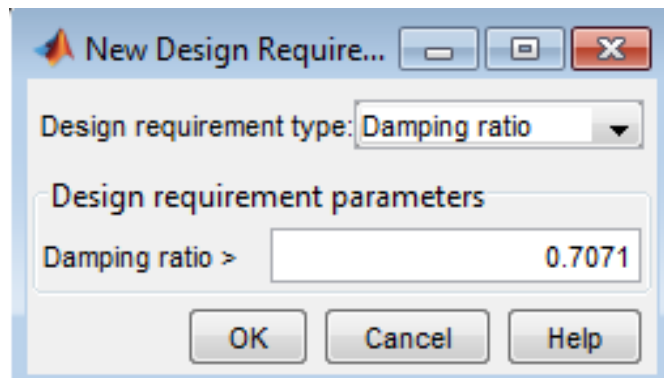
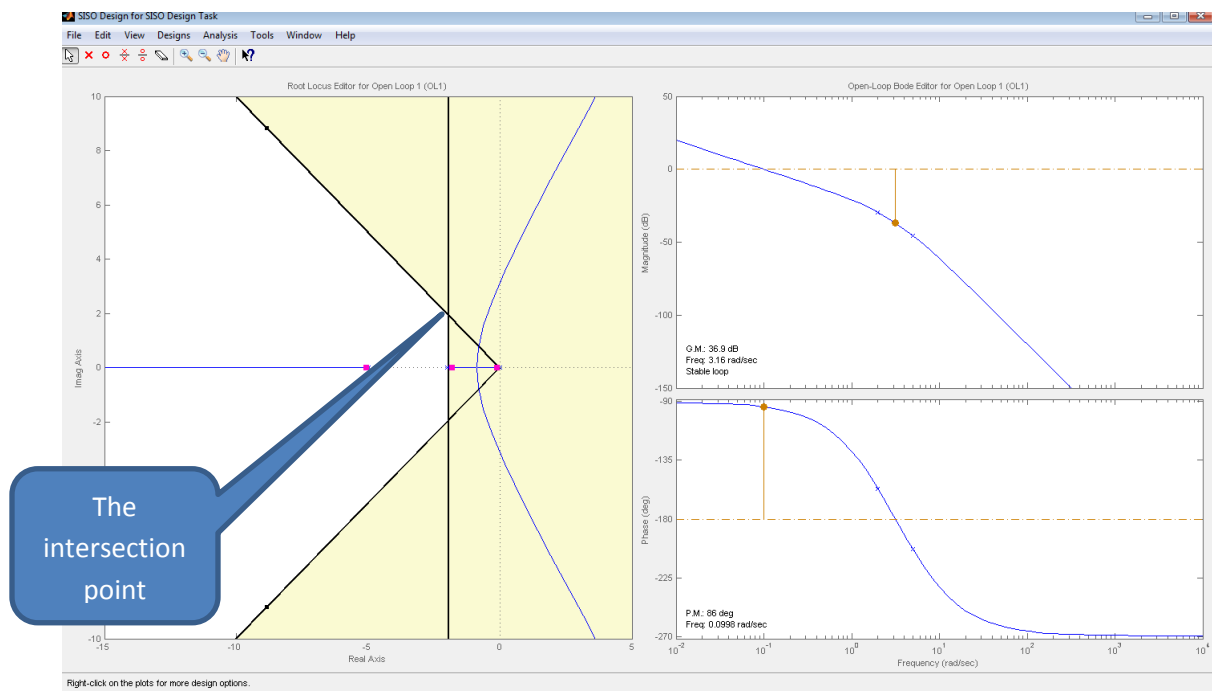


Figure 4change on the sisotool

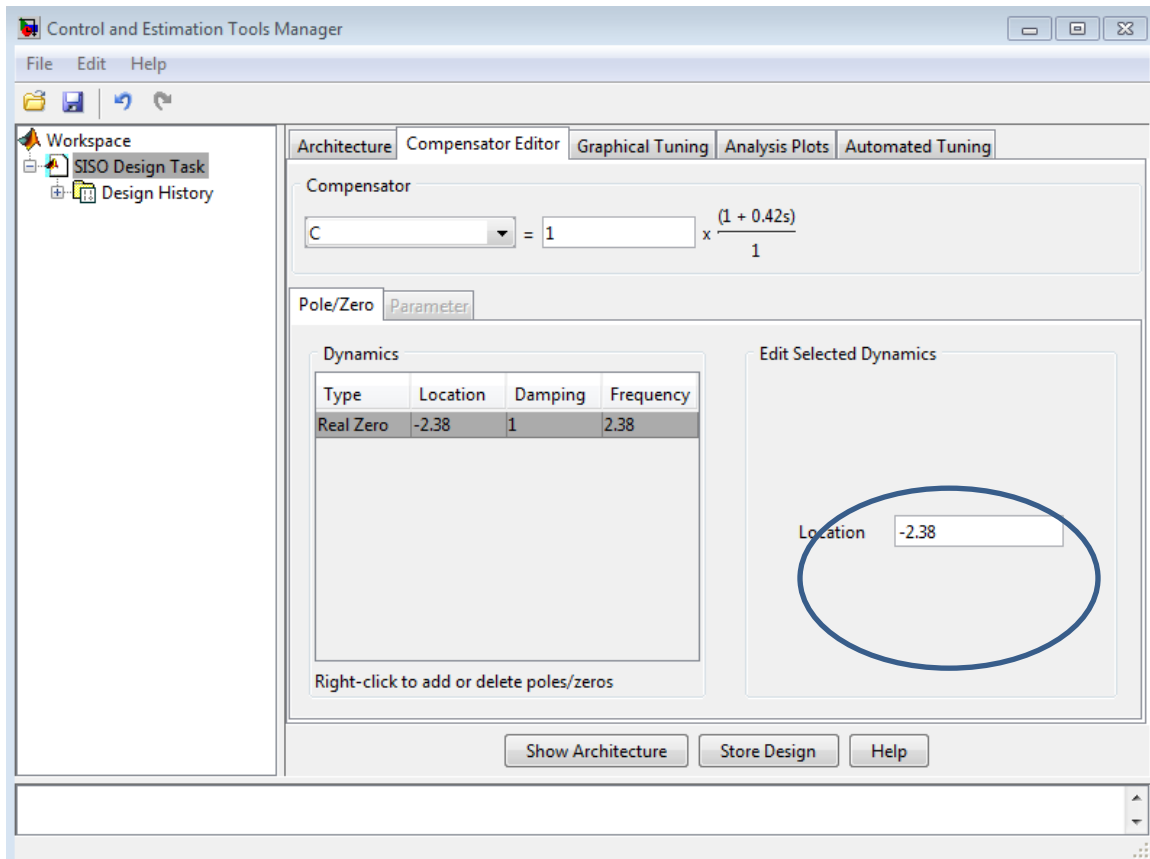
Now do the previous step one more tome put this time for damping ration



The following change will appear on the sisotool



The desire point is the intersection point and therefore we need the root locus to pass through this point by adding zero at -2.38 and in order to do that right click on the root locus and choose add real zero then go to the second screen and change its location



Step 4

Move the added zero until the root locus pass through the intersection point

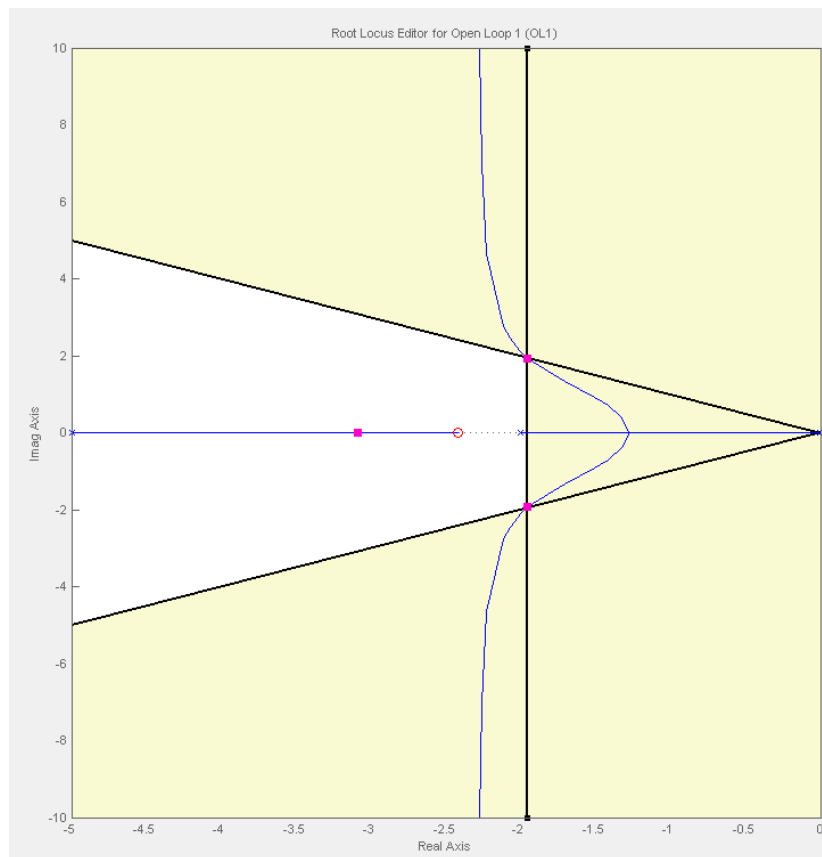
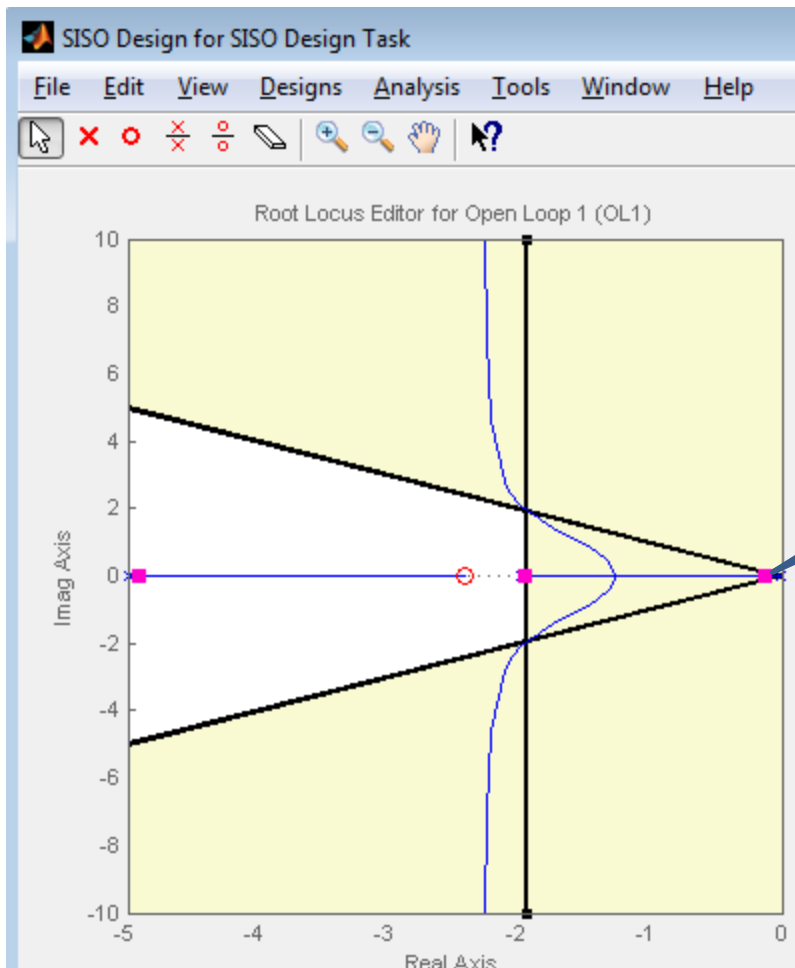


Figure 5 root locus pass through the intersection point

Now drag the close loop poles to the intersection point in order to find the rang of the gain require to reach the desire point



Now go the second screen and you will find the transfer function of the controller

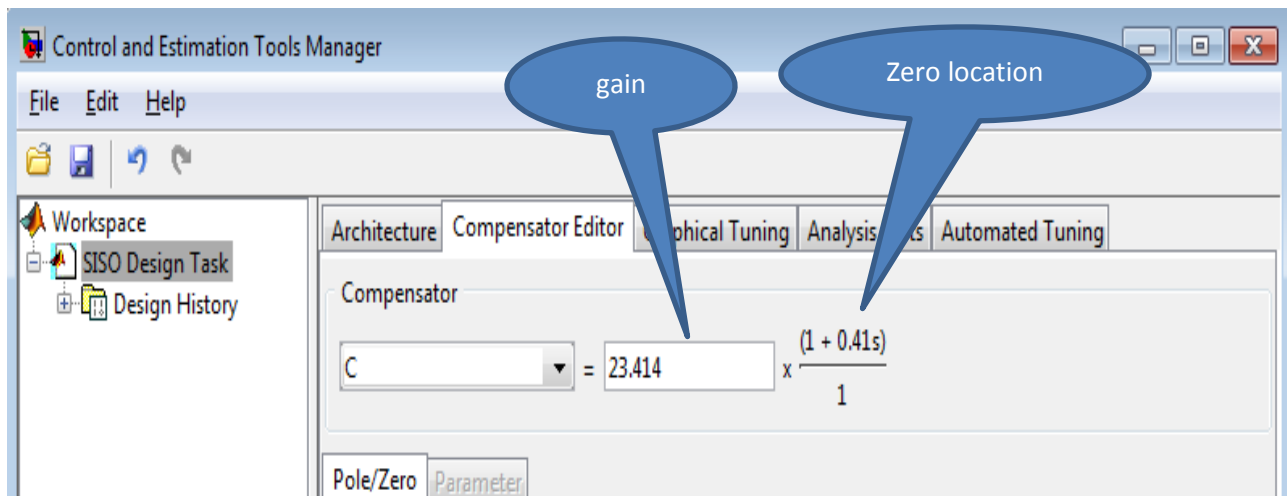
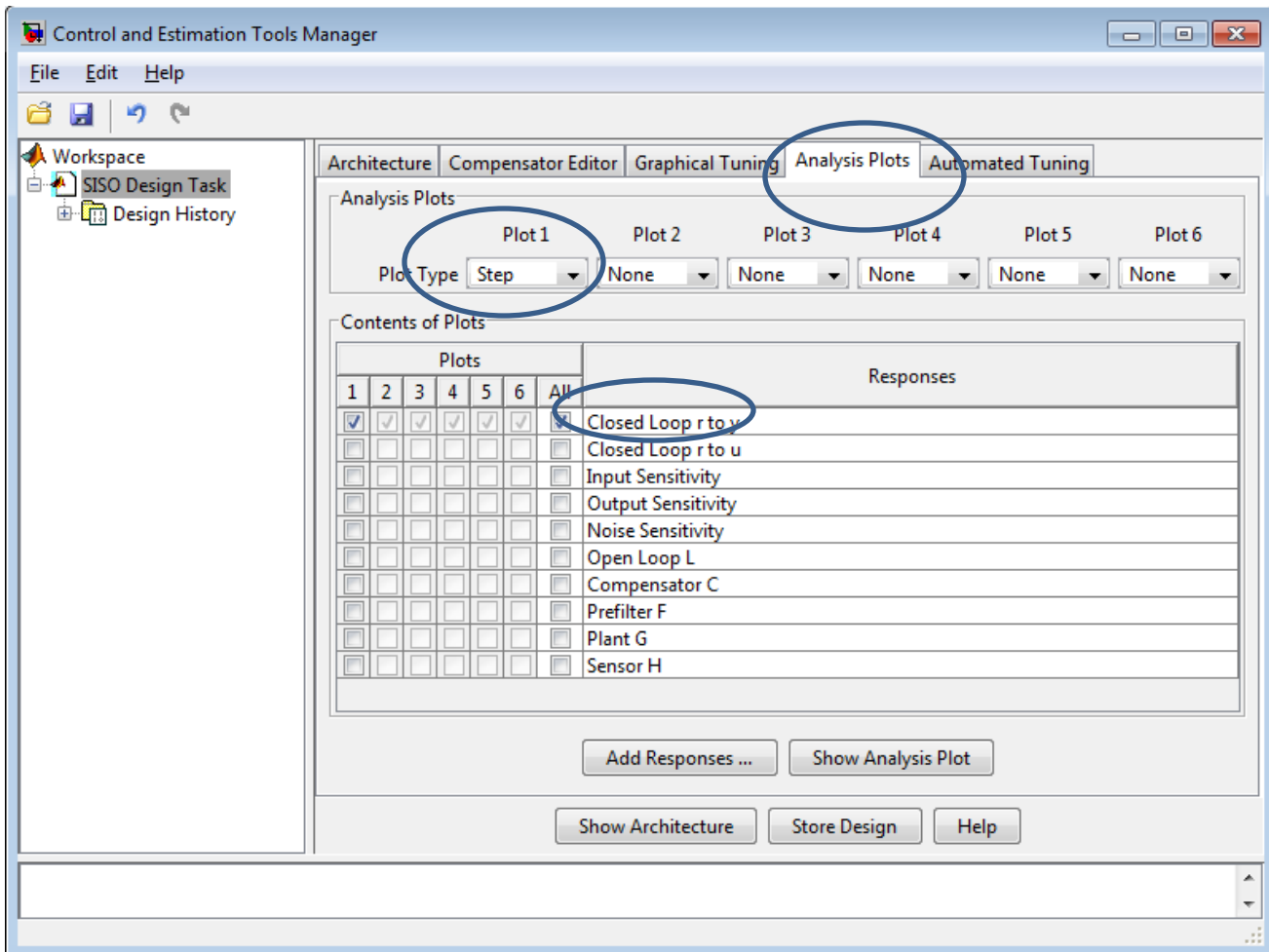


Figure 6 transfer function of the controller

How to make sure that the controller gives the required specifications?

Go to the second screen and choose **analysis plots** then choose the plot type which is step in **plot 1** then choose **close loop system r to y** and the step response will appear



Now right click on the step response and choose characteristics and from characteristics choose settling time peak time and other characteristics

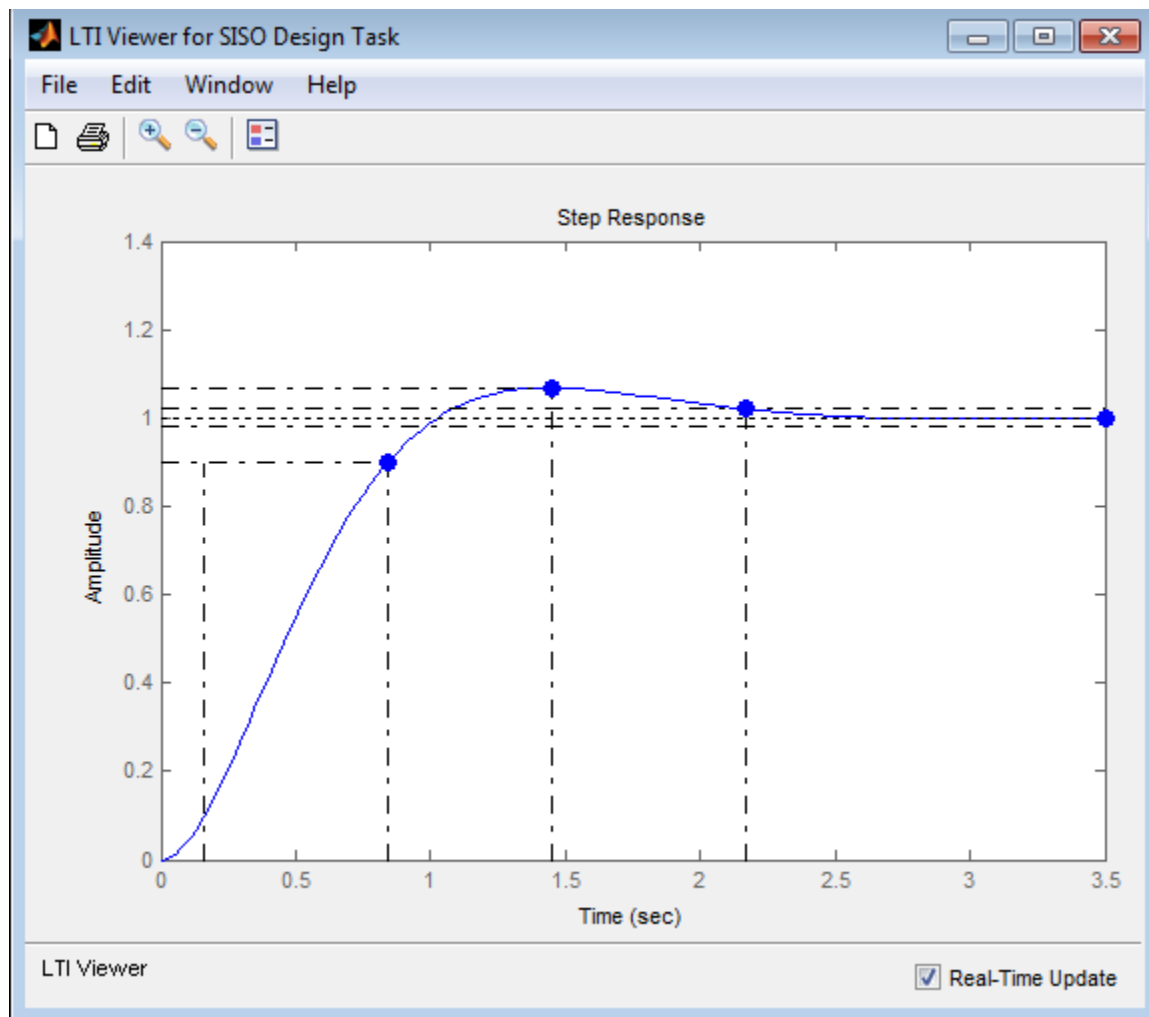


Figure 7 step response

If you need to design a PI controller for the system do the following

Add the PI controller transfer function before designing the PD controller

The PI controller transfer function is $\frac{s + 0.001}{s}$ from this transfer function

the pole is used to increase the system type and the zero used to preserve the root locus shape .

Report exercises:

1) Check your result of the example using Labview ?

Please add the block diagram in your report and the front panel and the step response and also the parameter of the step response like settling time over shoot and peak time for the system before and after controller?

2) Design a controller for the following system to get a damping ratio of 0.8, peak time of 1.047 s and the system should perfectly track a unit step.

Note: Using Matlab only.

$$G(s) = \frac{1}{(s + 1)(s + 4)}$$

3) Don't forget to write a summary for the experiment ..