Automatic Control Laboratory 610416

Laboratory supervisor :Eng.Esra'a Alghsoon

Laboratory Experiments

1	DC Servo motor (Input voltage versus Output speed)
2	Servo motor (Load versus speed)
3	Transient Response for DC Servo motor
4	Operational Amplifier as an error detector
5	Fundamental of closed loop system
6	Proportional -Integral controllers
7	Proportional –Integral-Derivative(PID) controller
8	Simulink MatLab
9	Error output in position control
10	Closed loop position control
11	Control for AC Induction motor

Control systems Laboratory

Prelab

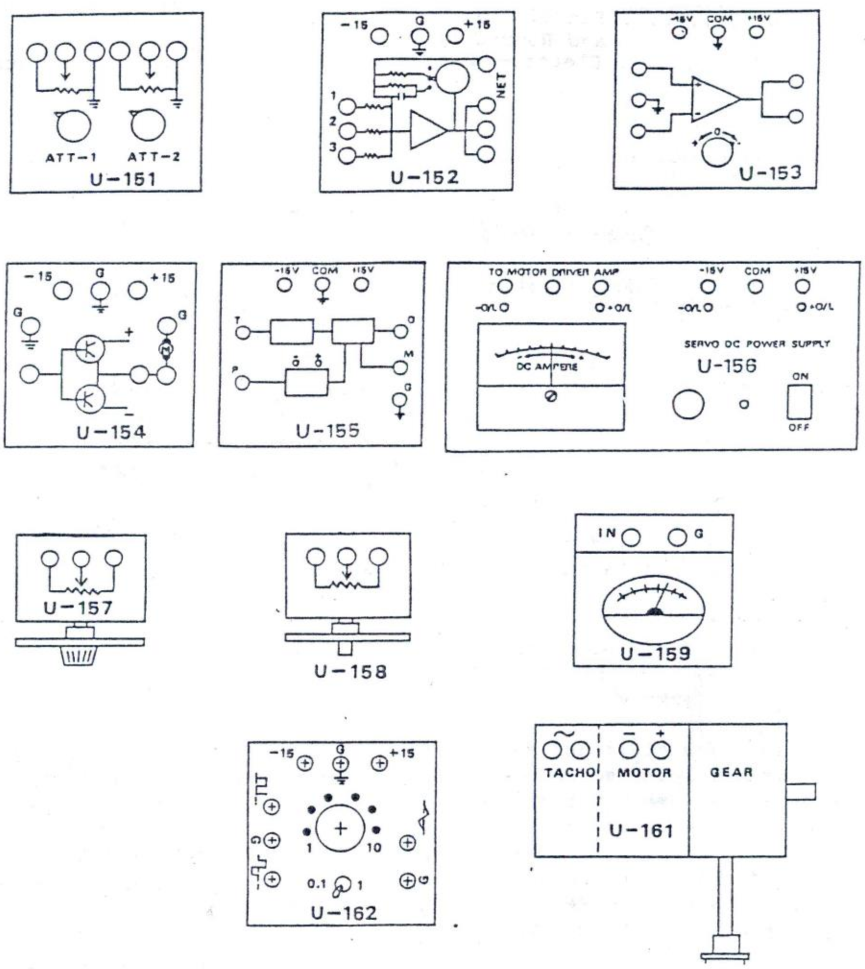
Student Name :

Student Number:

Experiment Title :

Objectives:

Circuit :



Graphical Identification of Each Module

Experiment 1

Motor speed Versus Input Characteristics

EXPERIMENT 1. MOTOR SPEED VS. INPUT CHARACTERISTICS

A. BACKGROUND THEORY

A direct current motor incorporates an amature winding connected to a commutator and magnetic poles which are excited from a DC source or which are permanent magnets.
Mechanical torque is generated when current flows through the winding. The magnetic circuits used in the DC motor in the ED-4400 are permanent magnets (constant magnetic field). Therefore, the speed of the motor strictly depends on the amount of voltage applied to the amature winding. (See Fig. 1-1).

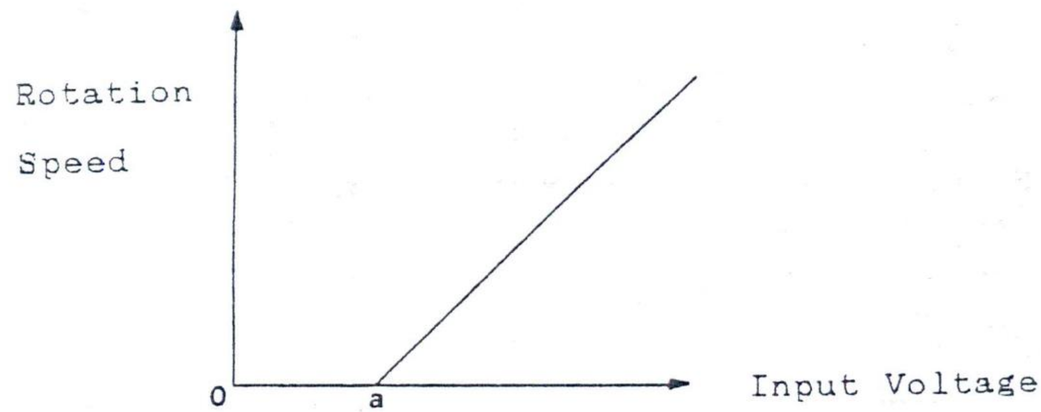


Fig. 1-1 Input Voltage VS. Motor Speed

As it is indicated by the point "a" on the X-axis, the motor requires a minimum input voltage to initiate rotating action. This is due to the mechanical frictions coming from brushes, bearings etc in the machine.

Increasing the input voltage increases the current through the winding and therefore, the speed of the motor.
However, the counter electromotive force on the amature coil is also increased as the speed of the motor is increased and finally the motor reaches a saturation point where any further increase in voltage no longer causes increase in speed.

The motor in the system is driven by U-154 motor driver amplifier.
Input voltage control is obtained through U-151 attenuator.
The speed of the motor, in RPM, is indicated on the U-159 meter by detecting the output of the tacho generator.

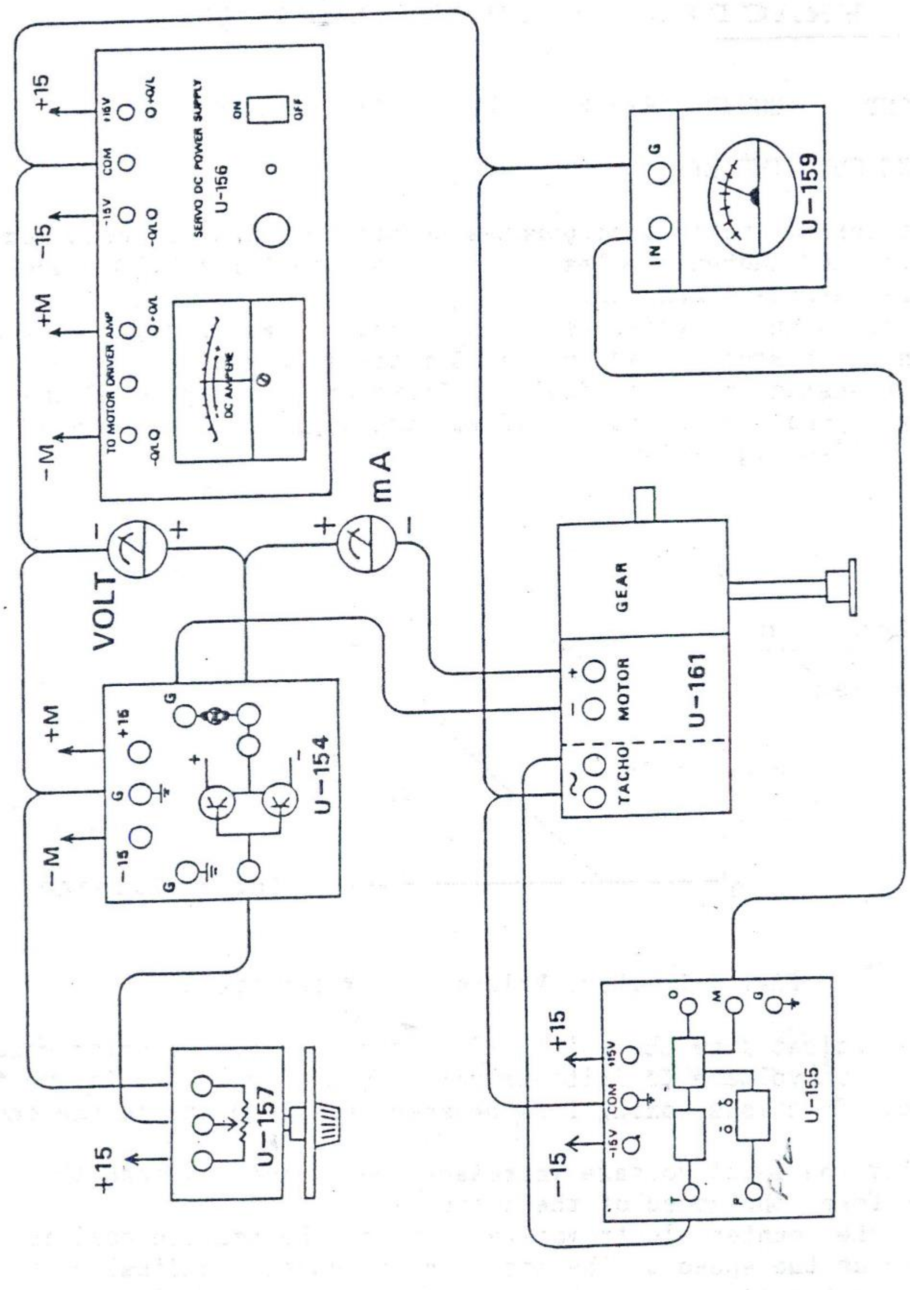


Fig. 1-2 Wiring Diagram of Experiment 1

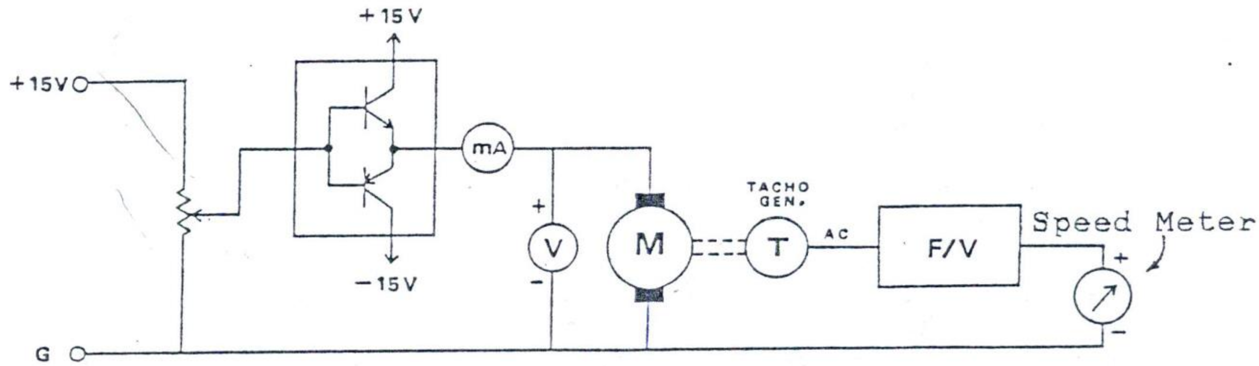


Fig. 1-3 Equivalent System Diagram of Experiment 1.

B. PROCEDURE

1. Refering to Figure 1-2, wire all the modules as needed on either a separate panel or on the top cover of ED-4400.

2. Connect the tacho-meter (U-159) accross terminals of meter and GND on U-155.

3. Set the dial on the U-157 to 180 degrees.

4. Plug in the power cord on the U-156 and turn the power switch on.

5. Turn the dial on the U-157 slowly counter clockwise untill the motor starts turning.
   Record the dial setting and the motor input voltage and the current.

6. Turn the dial on the U-157 clockwise and increase the input voltage by an increment of 1 volt each time and record the speed of the motor as indicated on the U-159 and the current to the motor.

7. Construct a graph by plotting the speed VS, the input voltage.
   Note : At some point, the speed reading on the U-159 will remain unchanged although the speed of the motor is still increasing. This is because the input to the U-155 is too much. Make sure the input does not reach this point.

8. Construct a graph by plotting the speed VS, the motor current and observe the relationship between the two.

9. The measurement error can be reduced by repeating steps 5 through 7 several times.

C. SUMMARY

1. The speed of the DC motor in the servo system varies almost linearly with the input voltage.

2. The current through the motor is not linear with the input voltage. At a saturation point, the motor current does not increase while the motor input voltage is still increasing. This is due to the counter-electromotive force (counter EMF) generated when the amature coil rotates in the magnetic field.

3. The motor exhibits so called "dead band" the minimum input voltage below which the motor can not turn.
This is due to the mechanical frictions between moving parts.

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Electrical engineering Department

Control systems Laboratory

610416

Experiment Title:

Experiments number :

Date:

Student Name:

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Supervisor Name: Eng.Esra'a Alghsoon

Introduction

Connect the modules that you need it in this experiment and follow the procedure steps on your manual to complete table below:

Motor speed	Input voltage	Motor Current

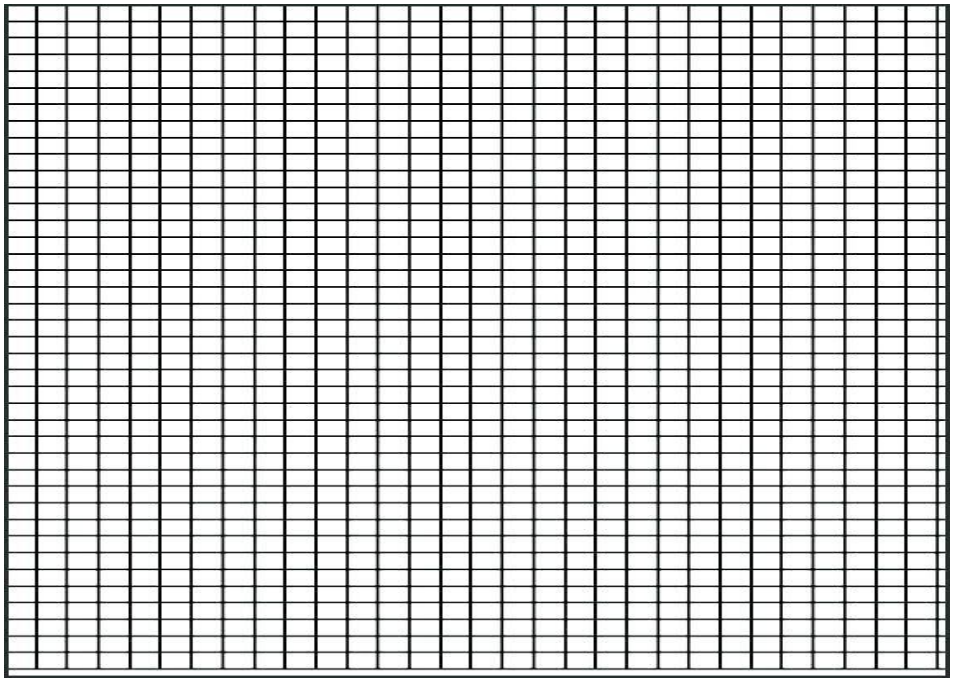
Construct graph by plotting speed versus the input voltage the write down your notes:

Notes :

1-

2-

Construct graph by plotting speed versus the motor current then write down your notes:



Notes :

1-

2-

Part 2:

• Carry out the circuit of figure 4.5.1

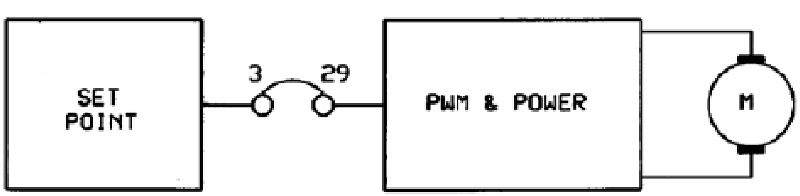


Fig. 4.5.1

• Jump terminals 26-27 to insert the clamp circuit.

• Set null load value with the knob of the mechanical brake

• Set a 0V voltage with the set-point and read the DIGITAL RPN NETER speed on the display

• Fill the table 4.1 with these data

• Repeat measurement f or all the voltage values on the table

• Bring the set-point voltage back to 0 V.

Voltage	RPM

Table 4.1

Notes:

Conclusion

Experiment 2

Motor speed Versus Load Characteristics

EXPERIMENT 2. MOTOR SPEED VS. LOAD CHARACTERISTICS

A. BACKGROUND THEORY

A typical output rating of a DC motor with permanent magnets ranges from several watts to almost one hundred watts.
This type of motor has relatively high efficiency.

The magnetic flux in the motor is constant because of the permanent magnets as magnetic ploes. Therefore, the torque of the motor is proportional to the input currents in the amature winding. The counter EMF is proportional to the speed of the motor at the same time.
The above relationships in the motor establish the following equations:

$$K\phi = \text{Constant} \quad (2\text{-}1)$$
$$E_a = K\phi\,\omega_m \ (V) \quad (2\text{-}2)$$
$$T = K\phi\, I_a \ (N.m) \quad (2\text{-}3)$$

where $K\phi$ = magnetic flux from the permanent magnets
E_a = counter EMF in volts
ω_m = angular speed of motor in rad/sec
T = torque in N.m
I_a = input current in amps

The relationships between the input voltage and the input current and between the speed and the torque are the following:

$$V_t = E_a + R_a I_a \ (v) \quad (2\text{-}4)$$
$$\omega_m = V_t/K\phi - R_a T/(K\phi)^2 \ (\text{rad/sec}) \quad (2\text{-}5)$$

where V_t = input voltage in volts
R_a = amature coil resistance

From the above equations, it can be seen that for a given input voltage, as the torque or the load increases, the speed of the motor decreases. Also, when the torque is increased, more currents are drawn through the coil. The relationship between the motor speed and the load is shown in Fig. 2-2.

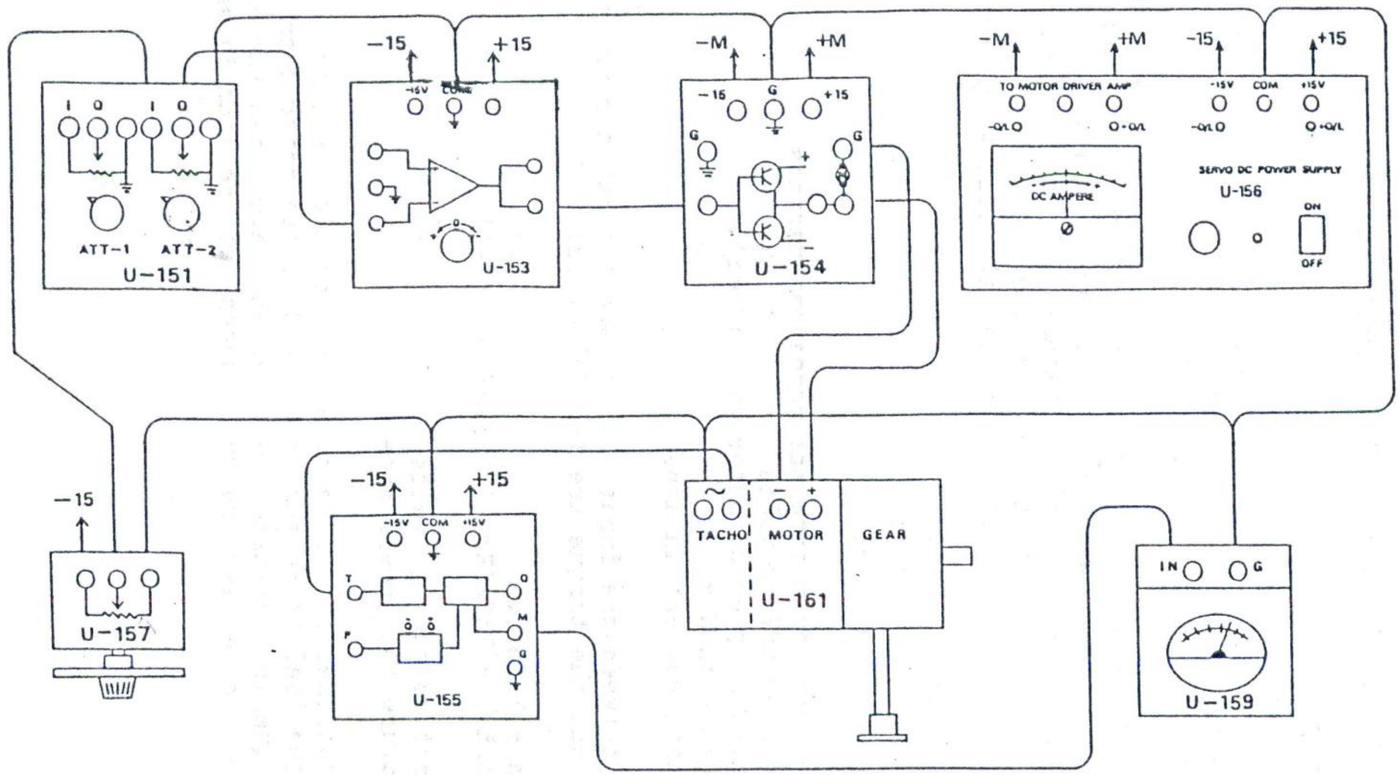


Fig. 2-1 Wiring Diagram of Experiment 2

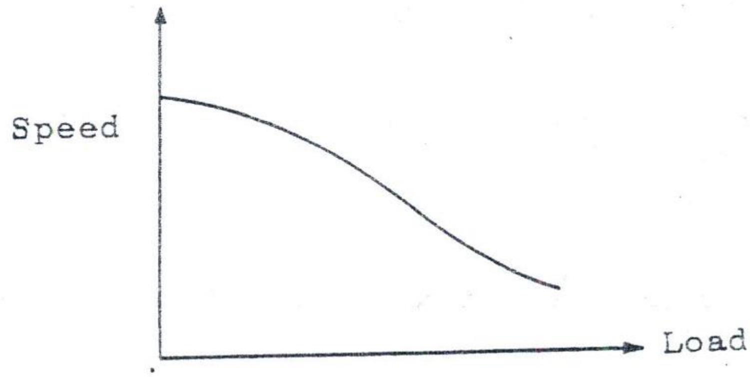


Fig. 2-2 Motor Speed VS. Load Characteristics

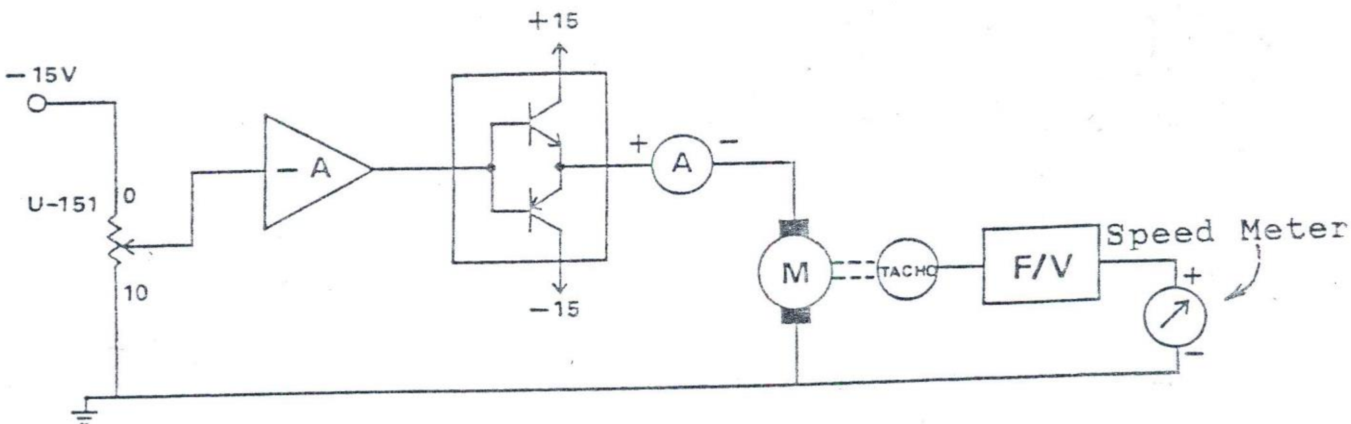


Fig. 2-3 Equivalent System Diagram of Experiment 2

B. PROCEDURE

1. Refering to Fig. 2-1, wire all the modules as needed.

2. Set the attenuaters on the U-151 to "8".
   Turn the power switch on. Adjust U-157 so that the U-159 indicates the maximum speed. Make sure the motor is not in the saturation mode.

3. Increase the brake position which is on the high speed axle of U-161 from 0 to one step up each time and record the RPM of the U-159 and the Motor current of the U-156

4. Decrease the brake position from 10 to one step down each time and record the RPM of the U-159 and the Motor current of the U-156

5. Using the data obtained through step 3 and 4, construct graphs of brake position VS. output voltage and brake position VS. motor current.

6. From these results plot the tacho voltage and current against the break scale setting.

C. SUMMARY

1. Mechanical loading to a DC motor reduces the sppeed and increases the motor current.

2. Overloading causes excessive currents which may cause damage to the motor. Remember that the motor dissipates power which is equal to the motor input voltage times the motor current.

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Electrical engineering Department

Control systems Laboratory

610416

Experiment Title:

Experiments number:

Date:

Student Name:

Student Number:

Supervisor Name: Eng.Esra'a Alghsoon

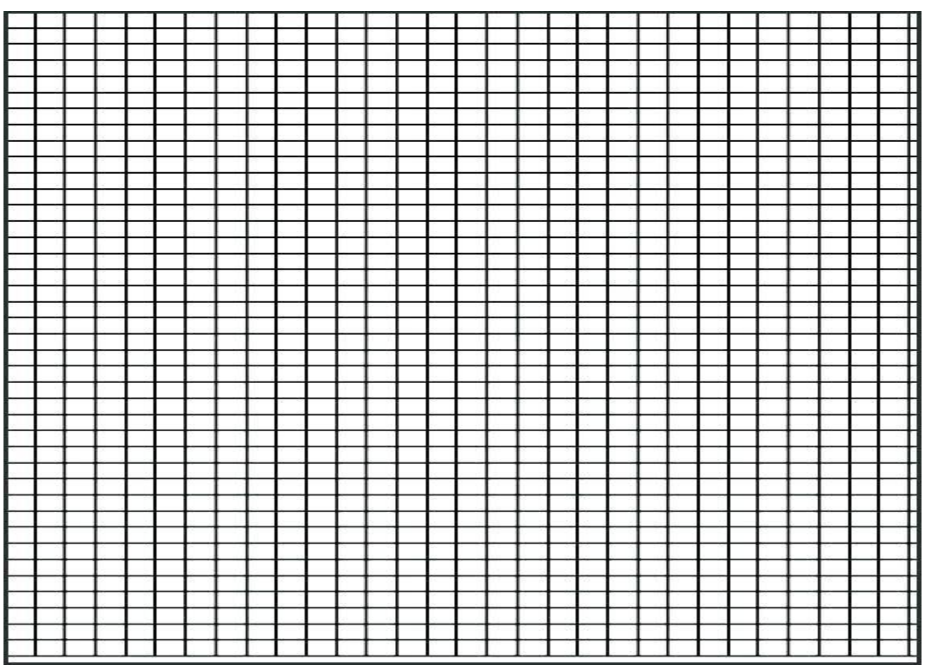
Introduction

Part 1:

Connect the modules that you need it in this experiment and follow the procedure steps on your manual to complete table below:

Motor speed	Brake setting	Motor Current

Construct graph by plotting speed versus the Load then write down your notes:



Notes :

1-

2-

Construct graph by plotting Load versus the motor current then write down your notes:

Notes :

1-

2-

Conclusion

Experiment 3

Transient Response of Dc servo motor

EXPERIMENT 3. TRANSIENT RESPONSE OF A DC MOTOR

A. BACKGROUND THEORY

The input applied to the motor in the previous experiments was a gradual one, thus the motor responded to the input without having distortion. However, when the input waveform is a step function, the motor can respond only with exponential characteristics.
Furthermore, when additional inertia is introduced to the rotating axle by adding a flywheel, the motor responds with additional delay.
The delay this case is bi-directional; when the input is reduced, the motor speed decreases with delay also.
Fig. 3-1 and 3-2 illustrate the relationship between the speed and the time with different values of inertia.

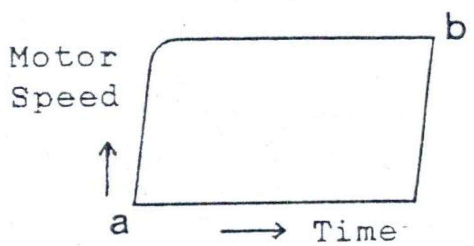


Fig. 3-1

Motor speed VS. time with small moment of inertia

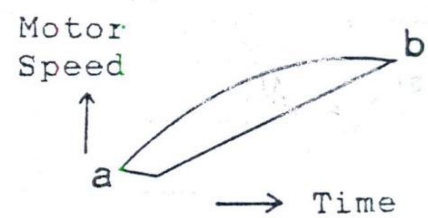


Fig. 3-2

Motor speed VS. time with large moment of inertia

The above output characteristics are obtained on the scope when the inputs to the motor and to the scope (X-input) are as shown in Fig. 3-4.

(a) Input to the motor (b) Input to the X-axis of the scope

Fig. 3-4 Input Signal Waveforms

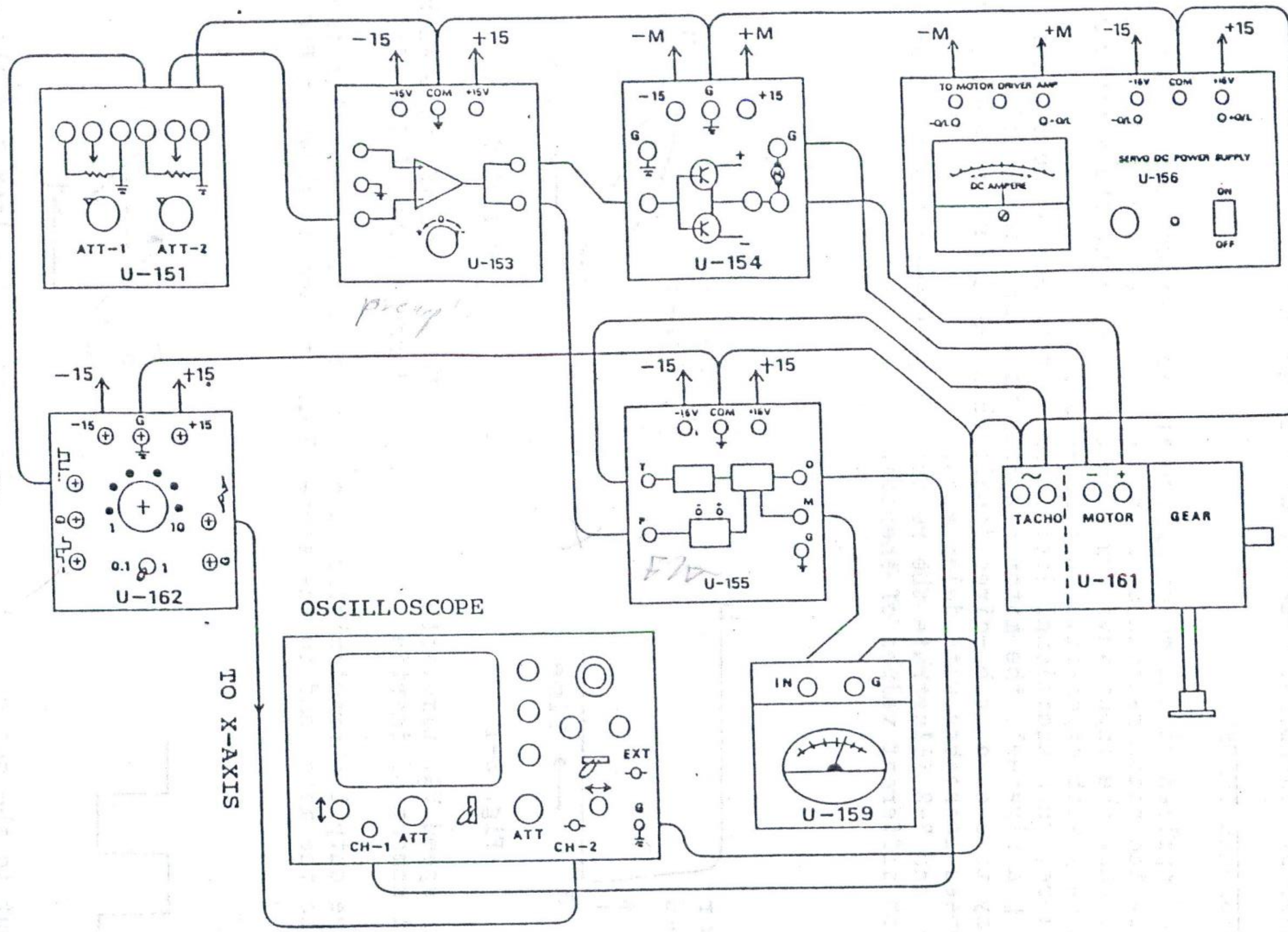


Fig. 3-3 Wiring Diagram of Experiment 3

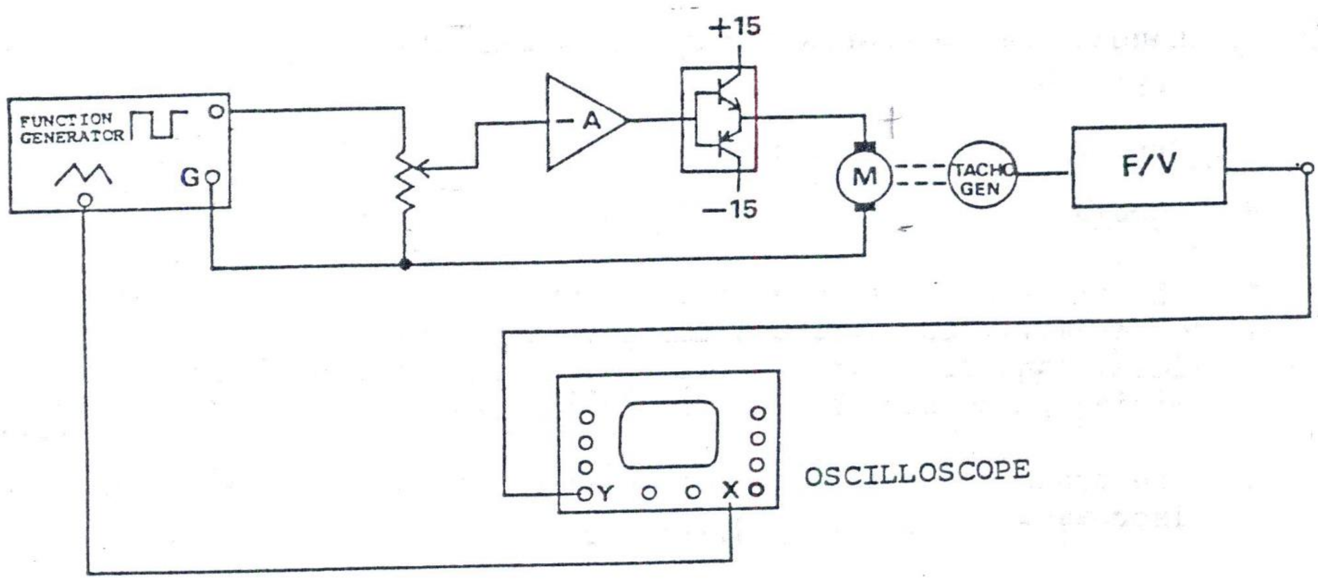


Fig. 3-5 Equivalent System Diagram of Experiment 3

B. PROCEDURE

1. Refering to Fig. 3-3, wire all the modules as needed.

2. Set the scope for X-Y operation. Connect the ramp output of the U-162 to the X-input of the scope.

3. Set the frequency of the U-162 to 0.1Hz.

4. Turn the U-156 on.

5. Adjust the display on the scope with the channel adjustors on the scope.

6. Adjust U-151 and keep the motor unsaturated (U-151 can be substituted with U-157 if necessary).

7. Adjust the display on the scope.

8. Observe the trace of the resultant X-Y display.

9. Turn the power off (on the U-156).
Connect a flywheel to the highspeed axle of the U-161.
Turn the power on and observe the trace on the scope.

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Experiment Title:

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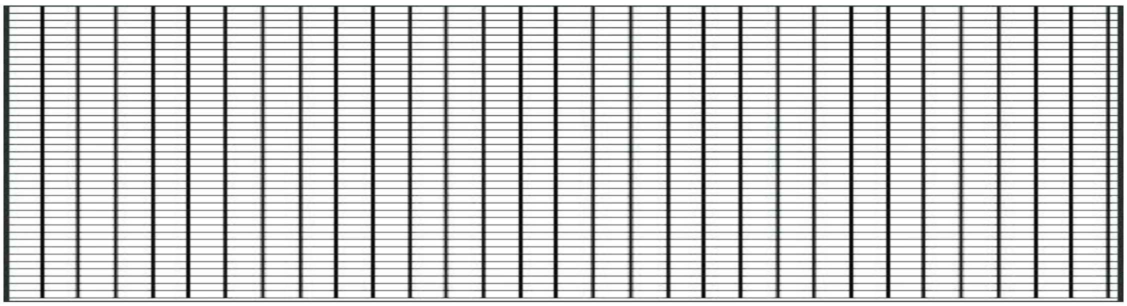
Supervisor Name: Eng.Esra'a Alghsoon

Introduction

Connect the modules that you need it in this experiment and follow the procedure steps on your manual.

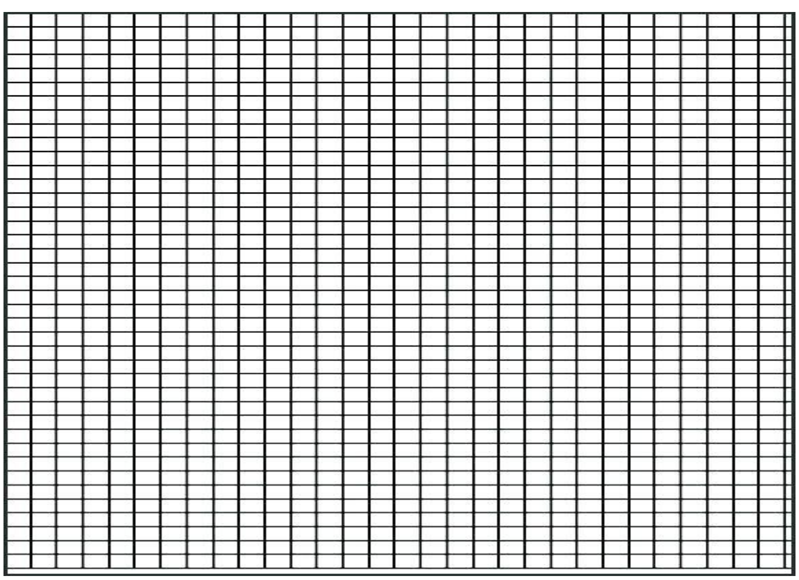
Plot the input voltage to the motor:



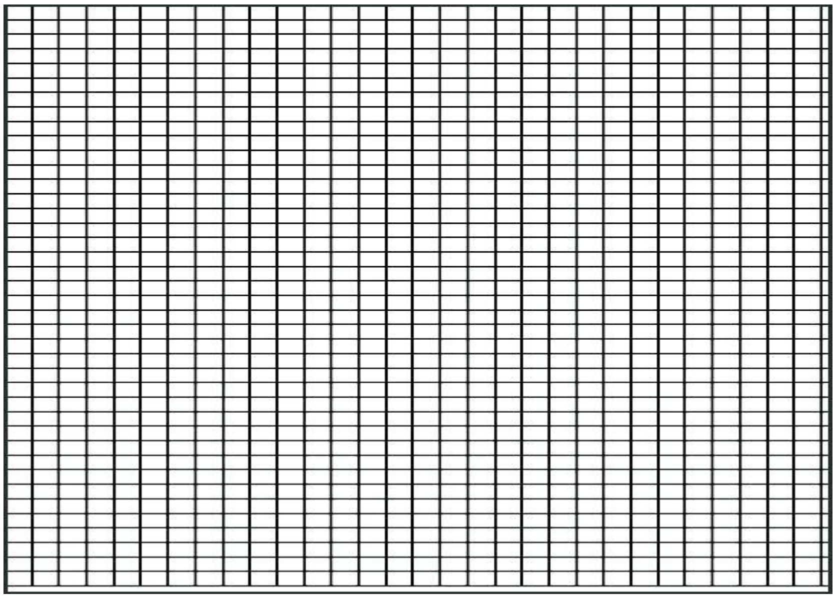
Plot transient response for the motor at A) Small moment of inertia

B) High moment of inertia

(A)



(B)



Notes :

1-

2-

Conclusion

Experiment 4

Operational Amplifier as an Error Detector

EXPERIMENT 4. OPERATIONAL AMPLIFIER AS AN ERROR DETECTOR.

A. BACKGROUND THEORY

The heart of the servo system is the error detector which detects the difference between the set value and the actual output of the system at any given time. The actual detection is done by taking the difference between the set value (same as input or reference) and the sample of the output value (or feedback signal) through an operational amplifier.

The operational amplifier in the ED-4400 is contained in the summing amplifier unit U-152. A SELECTOR SWITCH in the unit allows the user to select the desired configuration of the amplifier.

Some of the basic amplifier circuits are presented in Fig. 4-1.

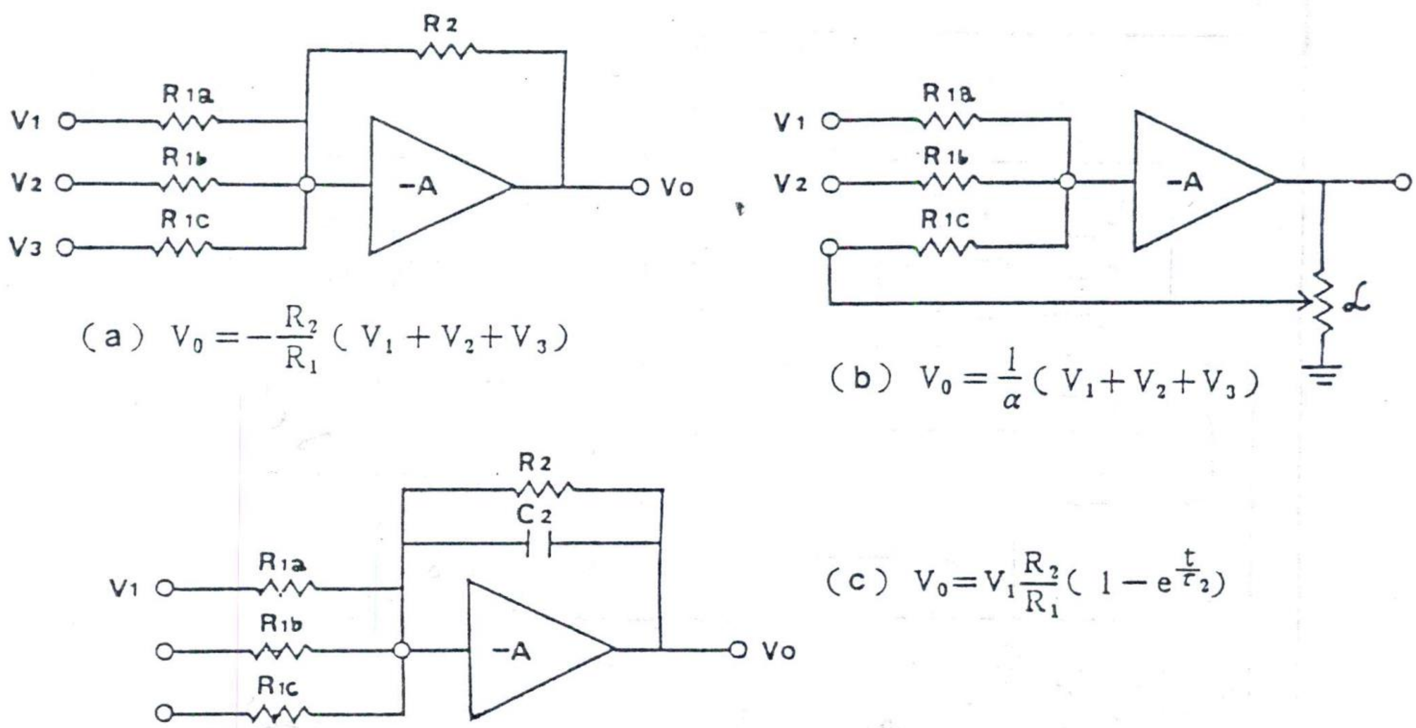


Fig. 4-1 Application Examples of Operational Amplifiers

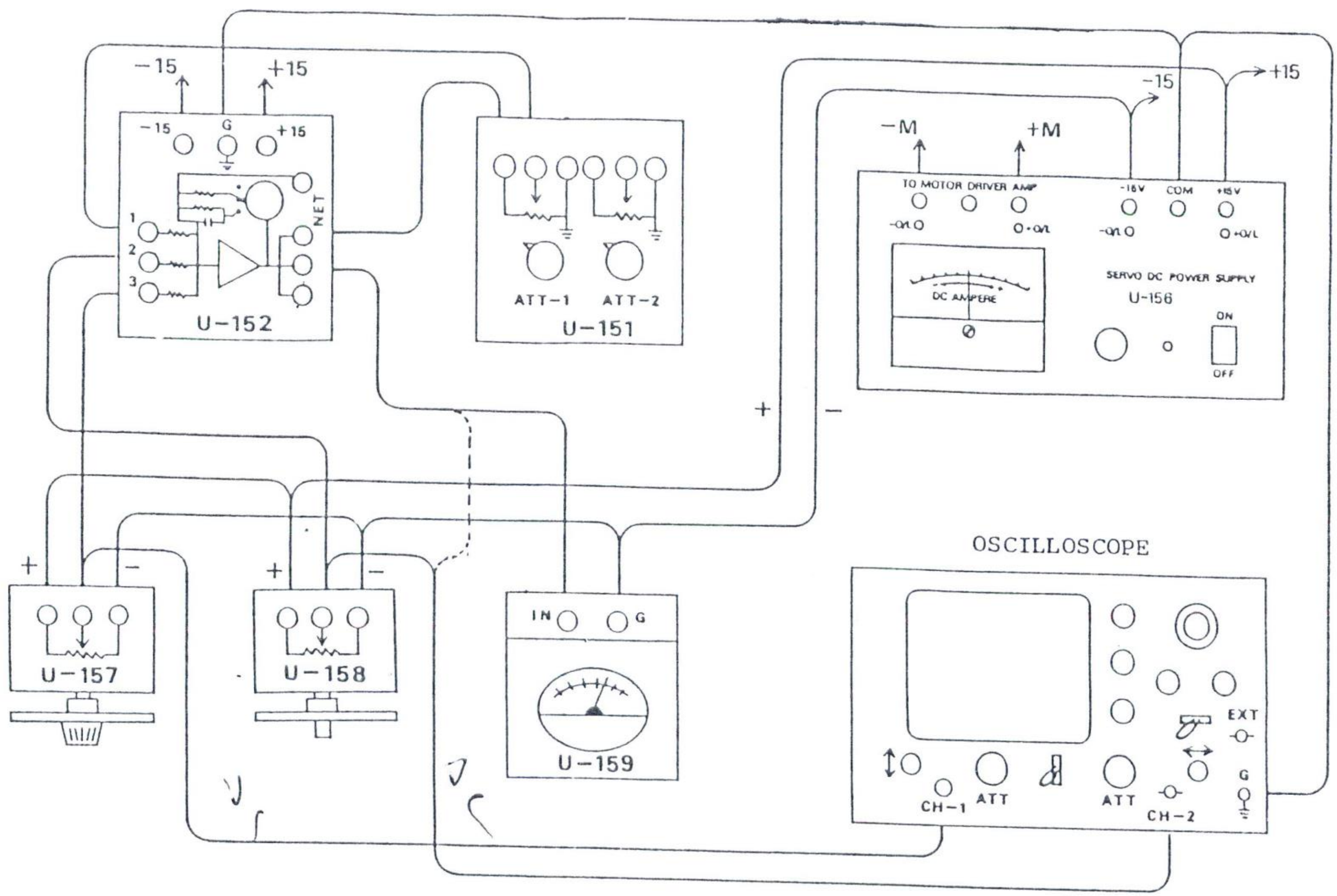


Fig. 4-2 Wiring Diagram of Experiment 4

The output of the amplifier in Fig. 4-1(a) is given by the following equation:

$$V_O = -\frac{R_2}{R_1}(V1 + V2 + V3) \text{ - - - - - - - } (4 - 1)$$

When R1a = R1b = R1c

In case R1 = R2, then the output Vo becomes simply the sum of V1, V2 and V3. The input to output relationships of the other two circuits are as expressed in each circuit diagram.
In all of the above examples. The Vo should not exceed 12V.

The above circuits as in Fig. 4-1 are readily available from the U-152 module:

1) Switch position "a" provides the same circuit as in 4-1(a).

2) Switch position "b" provides the same circuit as in 4-1(c).

3) The 4-1(b) circuit can be obtained by connecting U-151 to U-152 as shown in Fig. 4-2.

The 4-1(b) type of configuration will be used in our experiment.

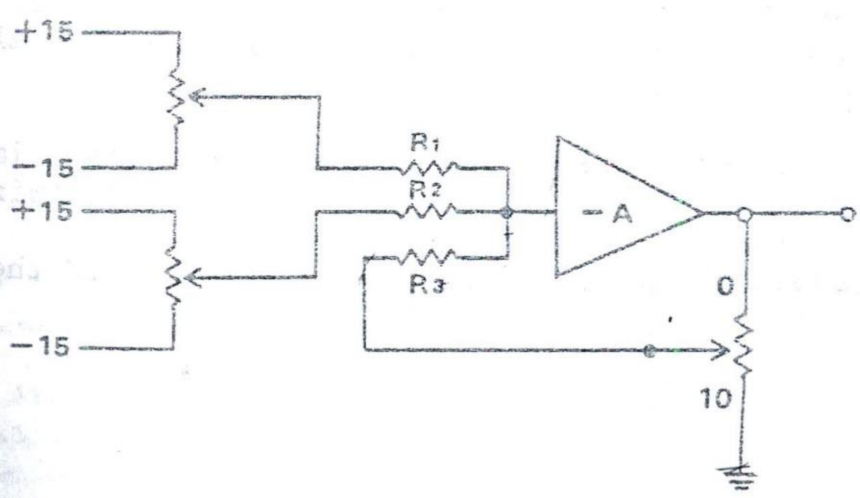


Fig. 4-3 Equivalent Circuit Diagram of Experiment 4

B. PROCEDURE

1. Refering to Fig. 4-2, wire all the modules as needed.

2. Set the selector SW. on U-152 to "EXT".

3. Turn U-156 on.

4. Using a voltmeter or a scope, set the voltage on the output terminal of U-157 and U-158 (1MΩ) to 0V.

5. Set U-151 to 0.

6. Measure the DC output voltage on the U-152.
The output should be very close to 0V (or less than 0.01V).

7. Adjust U-157 and U-158 so that the output is +1V.

8. Measure the output of U-152. Observe the relationship with inputs.

9. Set U-151 to 5. Measure the output of U-152.

10. Set U-151 to 0. Also adjust U-157 and U-158 so that the outputs are not the same between the two.
Measure and record the summed output on U-152.

11. Observe the output of U-152 as a function of U-151 position setting.
Find a case where the output becomes negative.

12. The "0" on the U-151 is for unity gain (gain = 1).
The gain is maximized at "10" on the U-151.

C. SUMMARY

1. An operational amplifier is a linear amplifier of which the output is propportional to the input and inversely proportional to the feedback signal.

2. Depending on the magnitude of the feedback, the input impedance of the operational amplifier can be very high, thus minimizing the loss of the input signal.
A precisely summed output, including the polarity of the signal, can be obtained using an operational amplifier.

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Experiment Title:

Experiments number:

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Introduction

Part 1:

Connect the modules that you need it in this experiment and follow the procedure steps on your manual to complete tables below then write down your notes :

Vx(input)	V1(input)	V2(input)	V (output)
0	0	0	
0	2	1	
0	3	1	
0	2	2	
0	3	3	
0	5	5	
0	10	10	

Notes :

1-

2-

V1=	V2=
X	V (output)
0	
1	
2	
3	
4	
5	
6	

V1=	V2=
X	V (output)
0	
1	
2	
3	
4	
5	
6	

Notes :

1-

2-

Conclusion

Experiment 5

Fundamental Closed Loop Speed Control

EXPERIMENT 5. FUNDAMENTAL CLOSED LOOP SPEED CONTROL

A. BACKGROUND THEORY

Quite often, needs rise in the application of DC motors such that once the speed of the motor is set, the motor maintains the same speed regardless of changes in the load.
In the closed loop speed control system, an error signal is developed between the desired motor speed and the actual motor speed at any given time. The error signal is amplified and feedback to the input to counteract to the output.

A system which has such a feedback mechanism is called a closed loop system. In the previsous experiments, the system was without feedback and such a system is called an open loop system.
Fig. 5-1 illustrates the basic difference between two system.

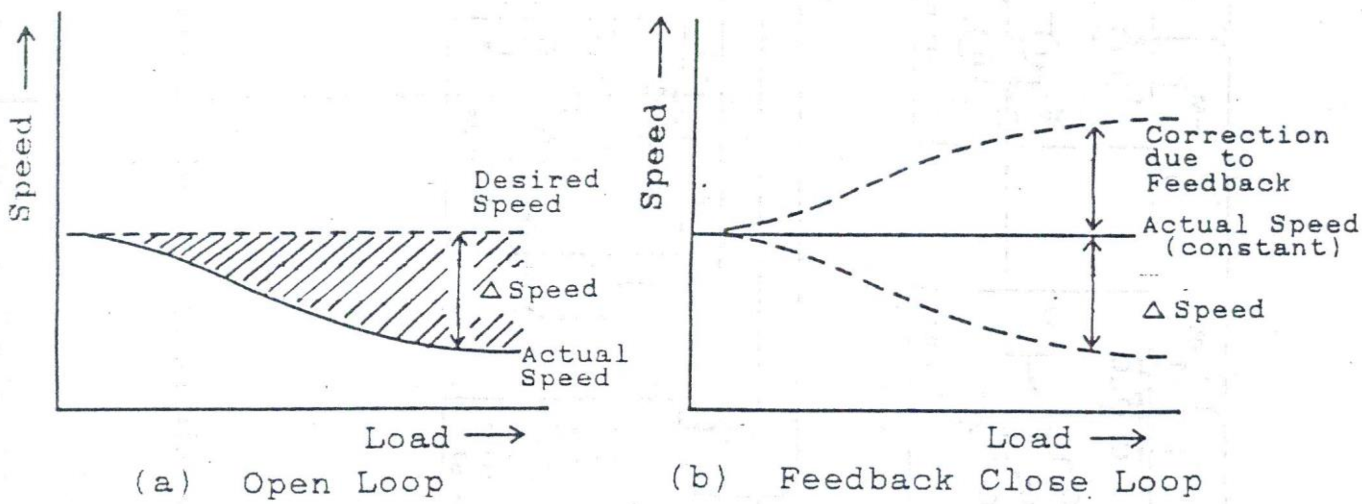
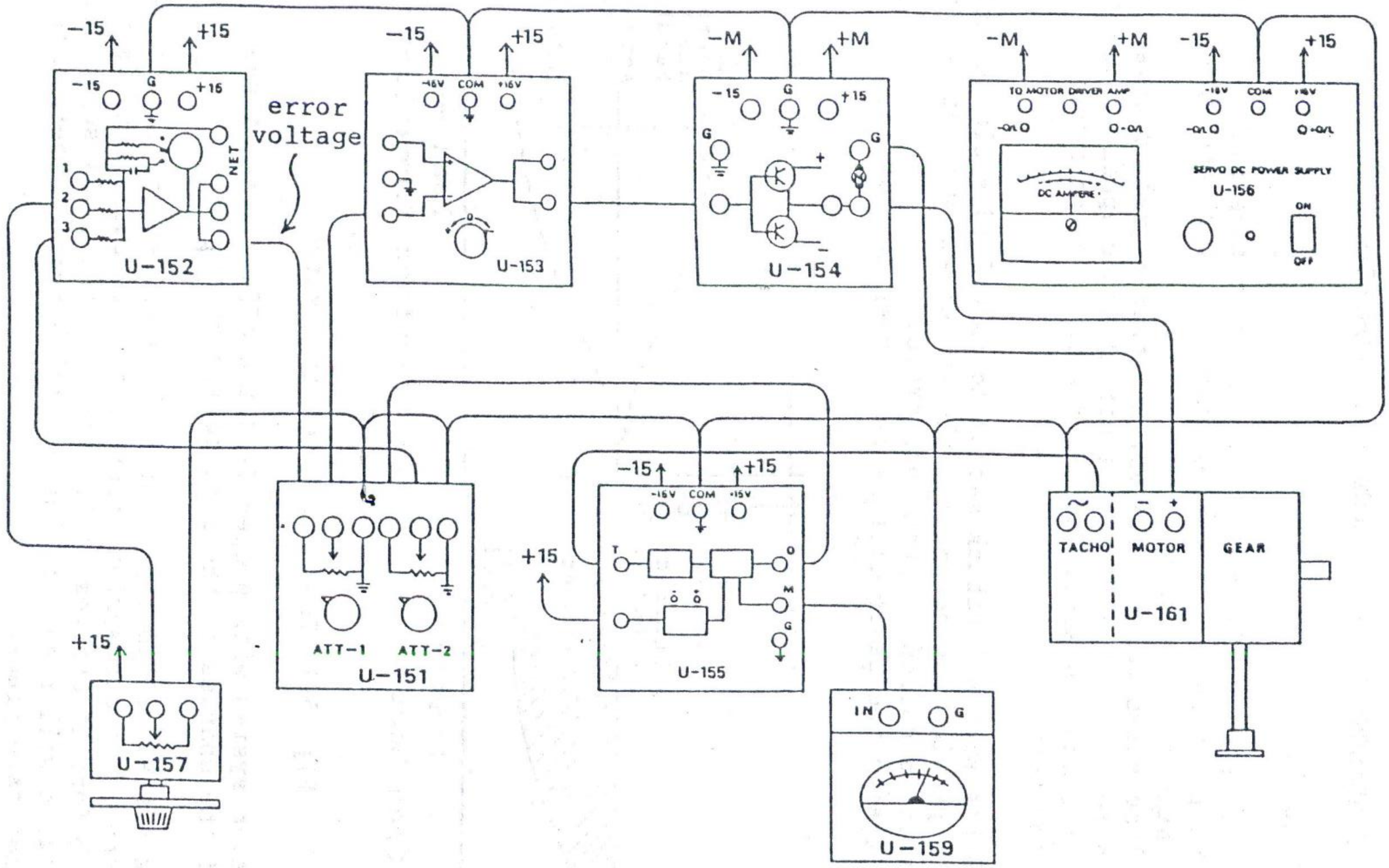


Fig. 5-1 Load VS. Speed in a Motor

As we can see, a system with proper feedback offers contant speed regardless of the changes in the load to the motor.

In a feedback system, it is important to have enough amplification of the error signal. In our system, there has to be sufficient gain to the error signal before it arrives at the input of the U-154 servo driver. Insufficient gain will result in "dead band" situation where automatic control can not take place.



· Fig. 5-2 Wiring Diagram of Experiment 5

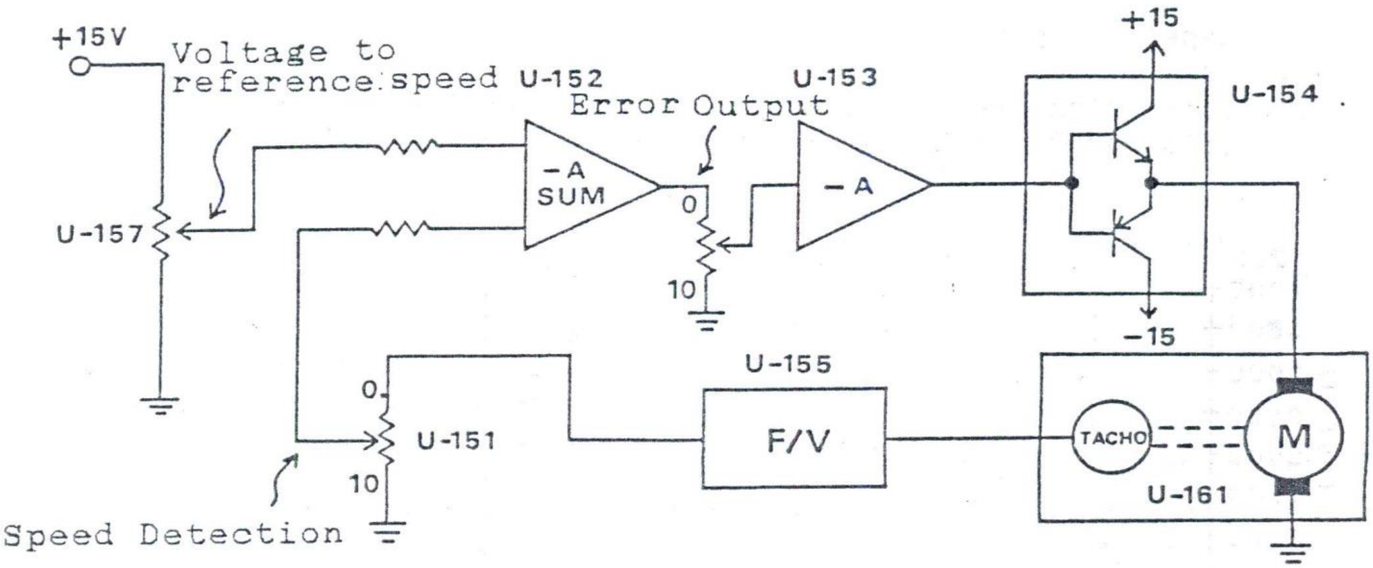


Fig. 5-3 Equivalent System Diagram of Experiment 5

B. PROCEDURE

1. Refering to Fig. 5-2, wire all the modules as needed.

2. Set the circuit selector on the U-152 to "a".

3. Set the ATT-2 on the U-151 to 10. This will keep the tacho output from being amplified. Set the ATT-1 to 5.

4. Turn U-156 on.

5. Adjust U-157 such that the speed of the motor is about one half of the maximum (this is equivalent to approx. 2500 RPM on U-159).

6. Increase the brake setting by one increment at a time and record the RPM of the U-159

7. Record the error voltage as a function of the brake setting. Note : At this point, there is no feedback (ATT-2 is set to 10) and therefore, the error voltage will depend on the input variation.

8. Reduce the ATT-2 setting to 5. Adjust U-157 to obtain the same speed as in step 5 (2500 RPM).

9. Vary the brake setting and at each time, record the value on the speed meter and the associated error voltage. Construct graphs of speed VS. brake and error voltage VS. speed (See Fig. 5-4(a) and (b)).

10. Set the ATT-2 to 0. Readjust U-157 to maintain the same speed.

11. Repeat step 9.

12. Compare the results from step 3 ~ 7 (open loop) to the results obtained through step 8 ~ 9 and 10 ~ 11 (closed loop).

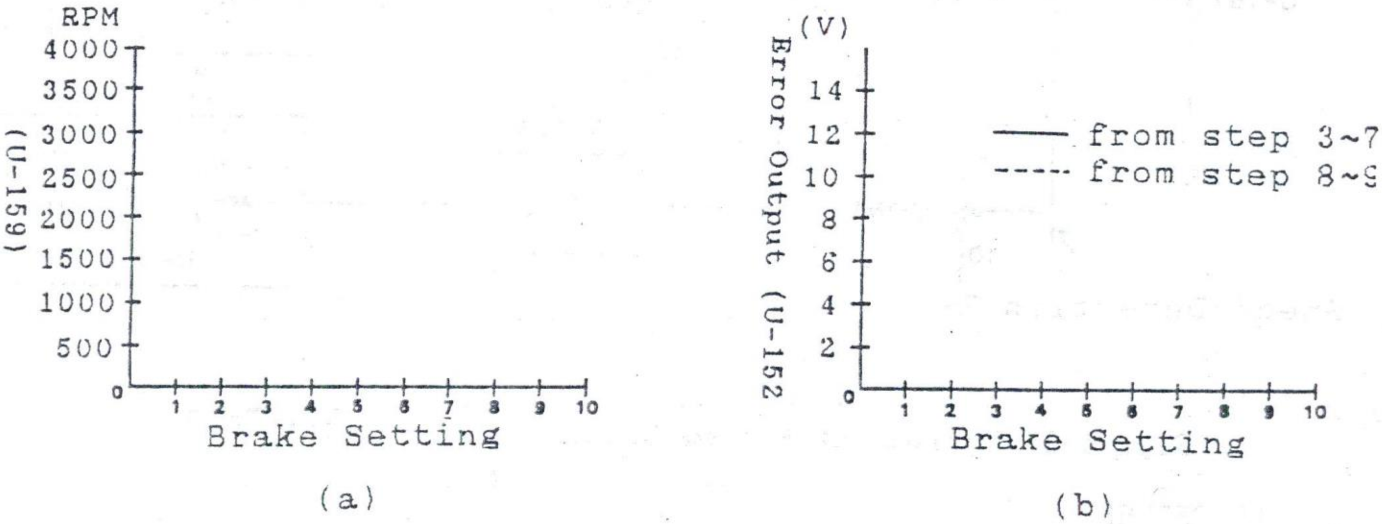


Fig. 5-4 Constructing Graphs for the Results

C. SUMMARY

1. In closed loop system, an error signal is generated.
The magnitude of the error signal is proportional to the magnitude of the reduction in speed when the load is increased.
The feedback of the error signal to the motor driver through an amplifier compensates the reduction in speed, thus maintaining a constant speed.

2. An excessive feedback signal causes reduction in speed from the desired constant value.
What this means is that the feedback signal which is applied to the summing amp. can not be greater than the input value which represents the desired speed. The feedback signal must be adjusted for the given load and the gain of the amplifier.

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Experiment Title:

Experiments number:

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Student Name:

Student Number:

Supervisor Name: Eng.Esra'a Alghsoon

Introduction

Connect the modules that you need it in this experiment and follow the procedure steps on your manual to complete tables below:

100% attenuation for feedback signal		
Motor speed	Brake setting	Error voltage

Construct graph by plotting speed versus the Load then write down your notes:

Notes :

1-

2-

Construct graph by plotting Load versus the error voltage then write down your notes:

Notes :

1-

2-

50% attenuation for feedback signal		
Motor speed	Brake setting	Error voltage

Construct graph by plotting speed versus the Load then write down your notes:

Notes :

1-

2-

Construct graph by plotting Load versus the error voltage then write down your notes:

Notes :

1-

2-

0% attenuation for feedback signal		
Motor speed	Brake setting	Error voltage

Construct graph by plotting speed versus the Load then write down your notes:

Notes :

1-

2-

Construct graph by plotting Load versus the error voltage then write down your notes:

Notes :

1-

2-

Conclusion

Experiment 6

P,I,PI controllers in
Closed loop system

EXPERIMENT 6: P,I,PI controllers in Closed loop system

EXPERIMENT OBJECTIVE

- To describe the proportional control mode;
- To describe the advantages and disadvantages of proportional control;
- To define residual error, proportional **gain**.
- To describe the integral control mode;
- To define the terms integral gain and overshoot;
- To describe the advantages and disadvantages of integral control;
- To describe the proportional-plus-integral control mode.

DISCUSSION

Closed-Loop Control

The addition of a controller and a feedback loop to a speed control system markedly reduces the Motor speed. This type of system, called closed-loop control system, is illustrated in Figure 4-1.

The controller compares the setpoint to the measured output and corrects for any difference between the two by modifying the setting until the system reaches a state of equilibrium

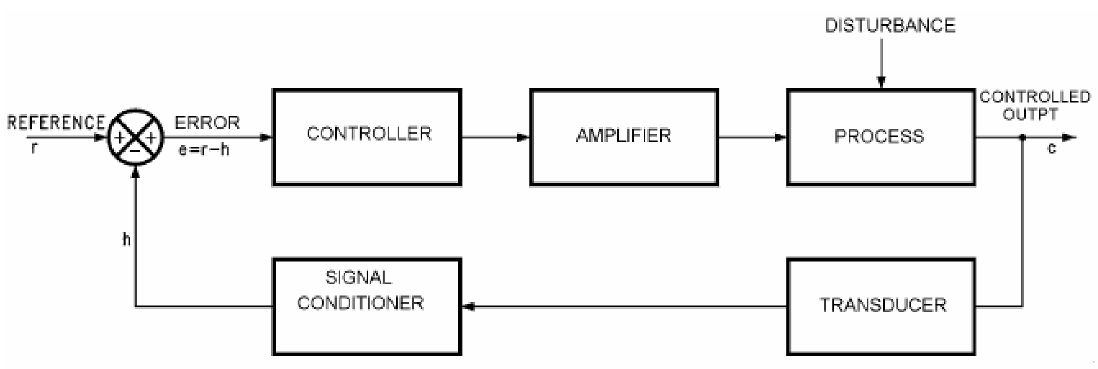


Figure 4-1. Closed-loop control.

The Control mode section performs mathematical operations which act on the error signal. The type of operations performed depends on the selected control mode. The control modes are the proportional (P) mode, integral (I) mode, differential (D) mode, or a combination of these. The resulting controller output signal is applied to the servo control Negative and Positive Feedbacks

Two types of feedback are possible in closed-loop control systems: positive feedback and negative feedback

- Positive feedback increases the difference between the setpoint and measured output. Positive feedback can result in violent and sustained oscillations within the system. For obvious reasons, positive feedback is not employed in closed-loop control,
- Negative feedback decreases the difference between the setpoint and measured output and acts to restore equilibrium

Implementation of Negative Feedback

In the system of Figure 4-1, negative feedback is implemented in the error detector section of the controller. This entails applying the setpoint signal to a positive (+) input of the error detector, and the position transducer signal (feedback) to the negative (–) input of the error detector. In this manner, the error detector output is equal to the setpoint value minus the signal corresponding to the measured value.

Proportional (P) Control Mode

As mentioned previously, the operation mode of the controller determines the type of mathematical operations performed on the error detector output signal in order to produce a change in the motor inputs The simplest control mode is the proportional (P) mode. Figure 4-3 shows the diagram of a controller operating in this mode:

- The error detector compares the feedback signal to the setpoint and produces an error signal EP equal to the difference between the two;
- The proportional amplifier amplifies the error signal by a factor KP to produce the controller output signal.

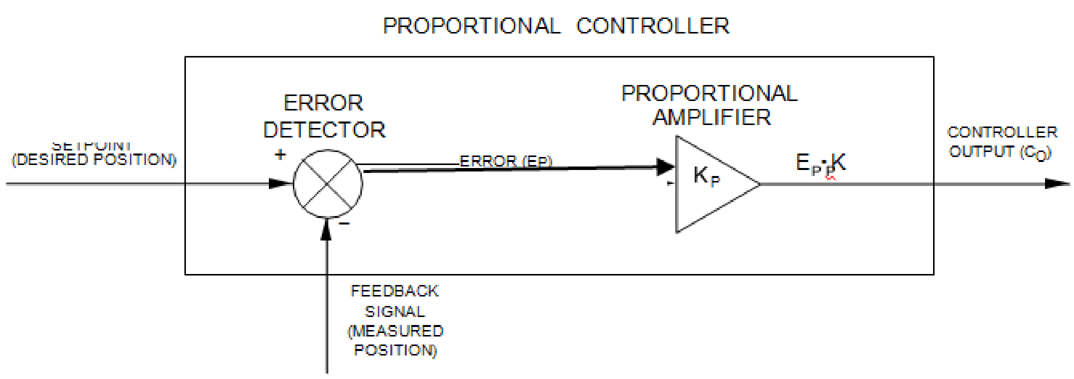


Figure 4-3. Diagram of a controller operating in the proportional (P) mode.

The controller output signal is proportional to the error signal at all times, hence the name proportional mode. The greater the error is, the greater the controller output will be. This relationship can be expressed mathematically:

$$C_O = K_P \times E_P$$

where C_O is the controller output;
K_P is the proportional gain;
E_P is the error.

The magnitude of the controller output signal is limited to the saturation levels of the proportional amplifier. If, for example, the saturation levels of this amplifier are +13.0 and –13.0 V, the controller output signal will never exceed these voltages. This means that once the controller output signal has reached one of the saturation levels, an increase in the error signal no longer produces an increase in controller output signal.

Advantages and Disadvantages of the Proportional Control Mode

The main advantage of the proportional control mode is the rapidity at which the controller responds to a change in error signal to return the system to equilibrium. The error greatly increases when the setpoint is changed, but the controller reacts immediately to correct this error. Since there is no delay in the response of the controller, the error rapidly decreases until the system reaches a state of equilibrium.

Once the system has reached the state of equilibrium, a residual error remains between the setpoint and measured variable. This is the main disadvantage of the proportional control mode. Reducing the error to zero would cause the controller output to be null. This would cause the valve input signal to be null and consequently the output pressure. Hence, a residual error is required to maintain the controller output at a desired value.

The higher the proportional gain K_P is, the lower the residual error will be. However, increasing the gain will also increase the system tendency toward instability. Indeed, if the gain becomes too high, the system will start to oscillate without being able to return to the state of equilibrium. Thus, increasing the gain is not the ideal solution to eliminate the residual error.

The Integral (I) Control mode:

While the proportional control mode looks at the "present" value of the process error, the integral (I) control mode regards the "past history" of the error by continuously integrating it until it is eliminated. Thus, the integral control mode automatically reduces the residual error to zero for any load change within the limitations of the system design

Figure 5-1 shows the simplified diagram of a controller operating in the integral mode:

- The "error detector" compares the measured output to the setpoint and produces an error signal equal to the difference between the two;

- The "integral amplifier", integrates the error to produce the controller output signal.

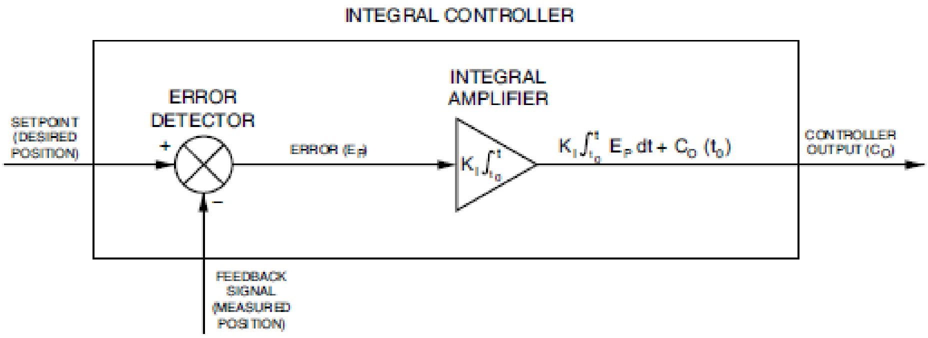


Figure 5-1. Simplified diagram of a controller operating in the integral (I) mode.

The output of the controller at any specified point in time, is given by:

$$C_O(t) = K_I \int_{t_0}^{t} E_P\,dt + C_O(t_0)$$

where CO (t) is the controller output at a specified time; KI is the integral gain;
EP is the error at a specified time;
CO (t0) is the controller output at the time the observation starts (t = 0).

The controller output signal is at all times proportional to the time integral of the error, hence the name integral mode.

Figure 5-2 shows an example of what happens to the signal at the output of an integral controller when the error is positive, negative, and null. The controller is in the open-loop mode. As you can see, when the error is positive, the controller output increases. When the error is negative, the controller output decreases. When the error is null, the controller output remains at the same level.

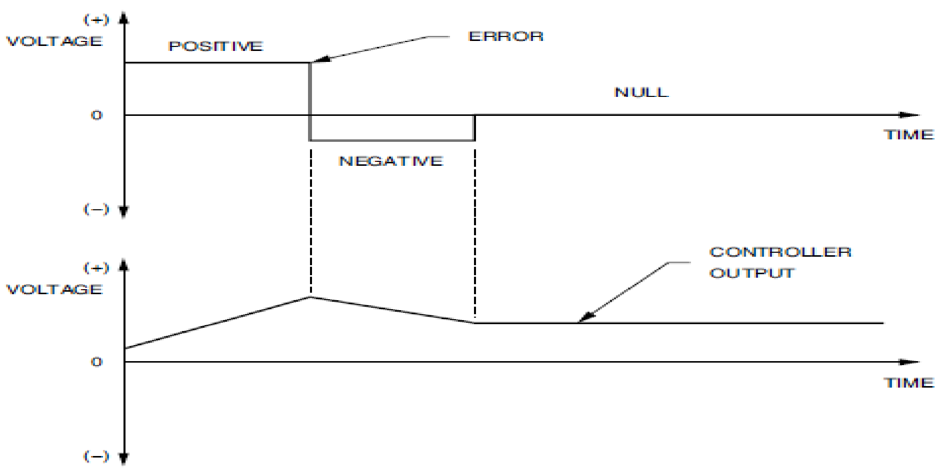


Figure 5-2. Controller output signals with positive, negative and null errors.

Integral gain

Figure 5-3 shows the output signal of an integral controller for different integral gain settings when the error changes suddenly. The controller is in the open-loop mode. The integral action causes the error signal to be transformed into a gradually changing signal at the controller output. The greater the integral gain KI, the greater the rate of change of the controller output.

The integral gain is expressed in number of repeats per minute (rpt/min). It corresponds to the number of times the magnitude of the error is duplicated at the controller output in a period of 1 minute:
With a gain of 5 rpt/min, the 1.0-V error magnitude is duplicated 5 times in 1 min. This means the controller output will be 5.0 V after 1 min (see Figure 5-3);

With a gain of 10 rpt/min, the 1.0-V error magnitude is duplicated 10 times in 1 min. This means the controller output will be 10.0 V after 1 min.

With a gain of 50 rpt/min, the 1.0-V error magnitude is duplicated 50 times in 1 min. This means the controller output will be 10.0 V after 0.2 min.

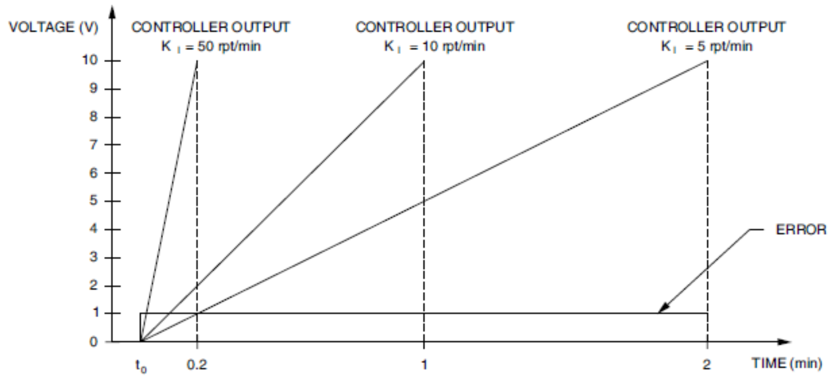


Figure 5-3. Output signal of an integral controller in the open-loop mode when the error changes suddenly.

Now suppose the integral controller is placed in the "closed-loop mode" in order to control a process. Figure 5-4 shows the effect of increasing the integral gain on the response of the controlled variable to a sudden change in setpoint. The higher the integral gain is, the shorter the time required to eliminate the error will be.

With a low integral gain as in waveform (a), the controlled variable is brought back to the new setpoint relatively slowly but with no overshoots. The system response is said to be “damped”. A damped response may be desirable in some applications.

Increasing the integral gain as in waveforms (b) reduces the time required to eliminate the error, but may also cause the controlled variable to overshoot the new setpoint before it stabilizes. However, small overshoots are usually tolerated in most applications.

Further increasing the integral gain results in higher overshoots, as in wave- form (c). Worse still, the time required to eliminate the error, instead of decreasing, actually gets longer because the controlled variable performs a number of oscillations about the setpoint before it stabilizes.

At very high integral gains, the system may even start to oscillate without being able to return to equilibrium, as in waveform (d).

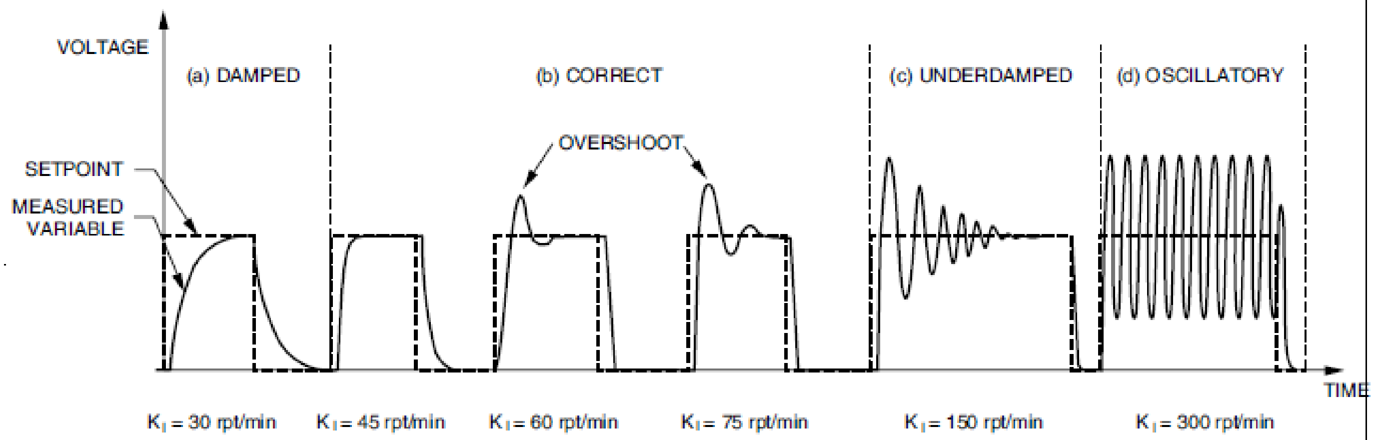


Figure 5-4. Effect of increasing the integral gain on the step response of a controlled variable.

The ability to reestablish a zero error is a unique characteristic of the integral control mode and is found in no other mode. However, the integral mode is normally not used alone, because of its relatively slow response at low integral gains, and because of the overshoots and increased risks of oscillation at higher integral gains. Instead, the integral mode is combined with the proportional mode to form the "proportional-plus-integral" control mode.

Proportional-Plus-Integral (P.I.) Control mode

The proportional-plus-integral control mode combines the fast transient response of proportional control with the zero residual error characteristic of integral control. It looks at the current value of the error and the integral of the error over a recent time interval to determine how much of a correction to apply, and also for how long.

Figure 5-5 shows the simplified diagram of a controller operating in the proportional- plus-integral mode. The error produced by the error detector is first amplified by a factor KP by the proportional amplifier. The proportionally amplified error (EP·KP) is then time integrated by the integral amplifier. Finally, the output signals of the proportional and integral amplifiers are added at a summing point to produce the controller output signal.

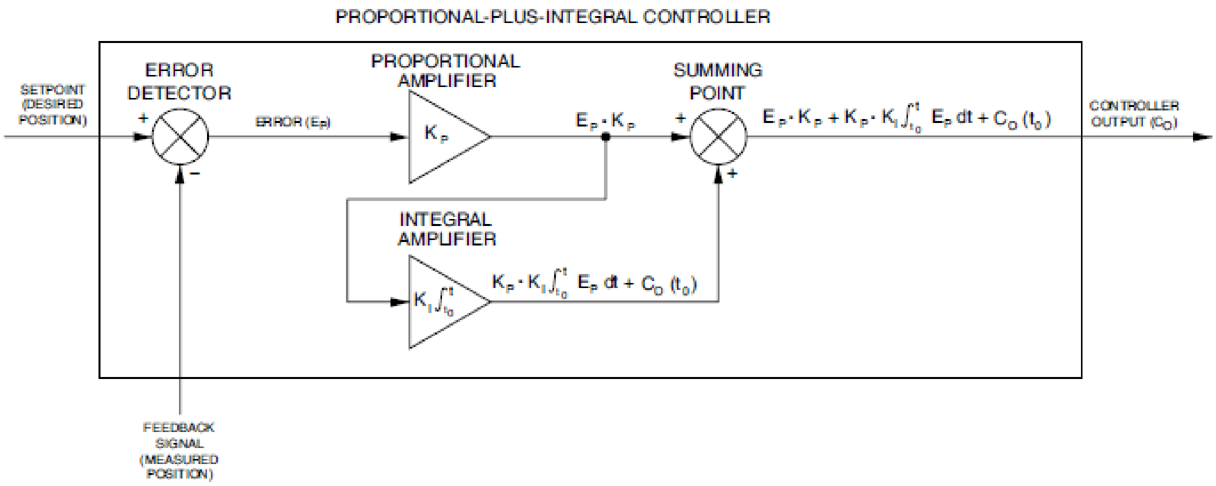


Figure 5-5. Simplified diagram of a controller operating in the proportional-plus-integral (P.I.) mode.

The controller output at any specified time, t, is given by:

$$C_O(t) = E_P \times K_P + K_P \times K_I \int_{t_0}^{t} E_P \, dt + C_O(t_0)$$

where CO (t) is the controller output at a specified time;

EP is the error at a specified time;

KP is the proportional gain;

KI is the integral gain;

CO (t0) is the controller output at the time the observation starts (t = 0).

In this equation, the term "EP × KP" describes the proportional action of the controller, while the rest of the equation describes the integral action of the controller, starting at time t = 0. Thus, the controller output is not only proportional to the error, but also to the time integral of the error.

Figure 5-6 shows what happens in a proportional-plus-integral control system when the error changes suddenly, due to a sudden increase in setpoint or actuator load. The proportional action quickly responds to the sudden change in error, while the integral action integrates the error until it becomes null. The higher the integral and proportional gains are, the faster the error will be eliminated. However, these gains must be kept low enough to prevent excessive overshoots, and to ensure system stability.

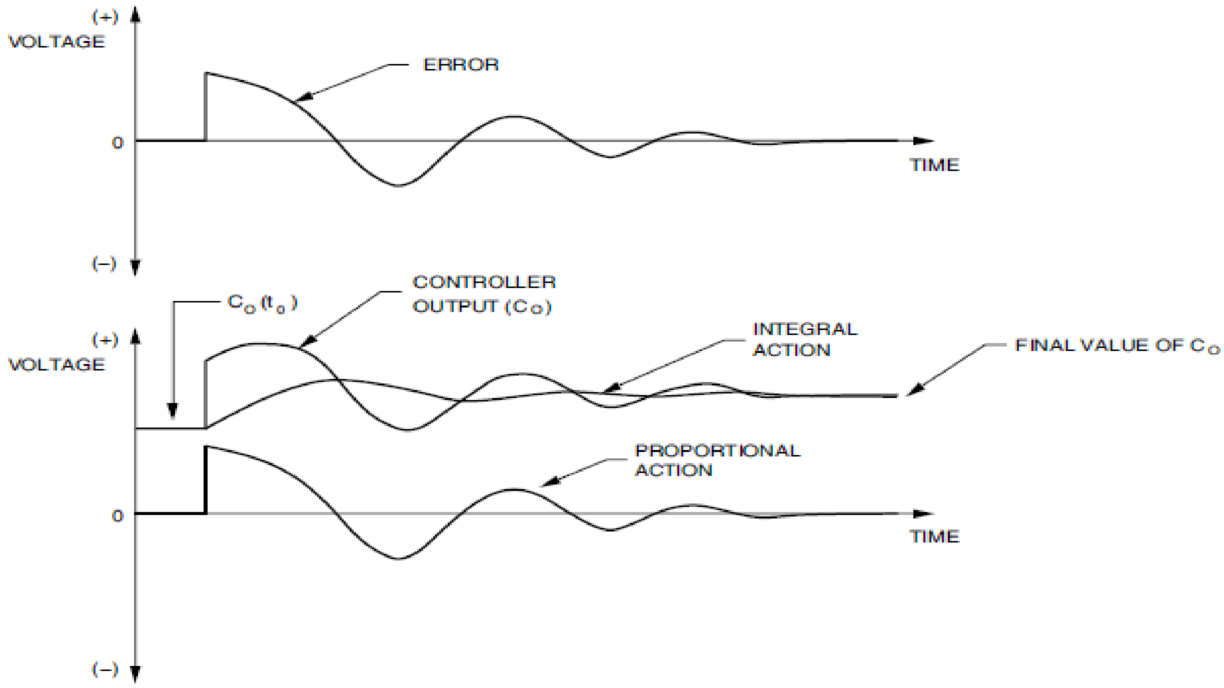


Figure 5-6. Example of what happens in a proportional-plus-integral control system when the error changes suddenly.

A problem related to the use of integral control is the "reset windup". Reset windup occurs when the error remains large during a long interval of time, causing the controller output to increase to the upper saturation limit (positive error) or decrease to the lower saturation limit (negative error). Afterwards, the controller cannot return to normal operation until the error reverses polarity, resulting in high overshoots of the controlled variable. For that reason, controllers usually have an "anti-reset" function that turns off the integral action as soon as the controller output reaches the upper or lower saturation limit, thus minimizing overshoots of the actuator position.

Comparison of the Proportional, Integral, and Proportional-Plus-Integral Control Modes

Figure 5-7 shows an example of the response of a typical process to a step change in setpoint with proportional, integral, and proportional-plus-integral control modes :

- The proportional mode reacts much faster than the integral mode. However, the proportional mode results in a residual error between the actual rod position and the new setpoint;
- The integral mode eliminates the residual error, but it reacts slower than the proportional mode, and it requires a longer time to reach the final value;

- The proportional-plus-integral mode reacts much faster than the integral mode, and it eliminates the residual error of the proportional mode. However, the addition of integral action to proportional action increases the overshoot and stabilization time.

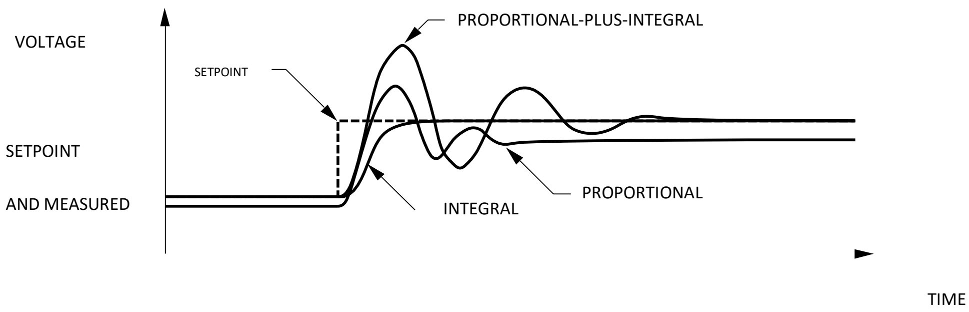


Figure5-7.Responsetoastepchangeinsetpointwithproportional,integral,andproportional-plus- integral control modes.

Important parameter:

Delay Time (Td): is the time required for the response to reach 50% of the final value.

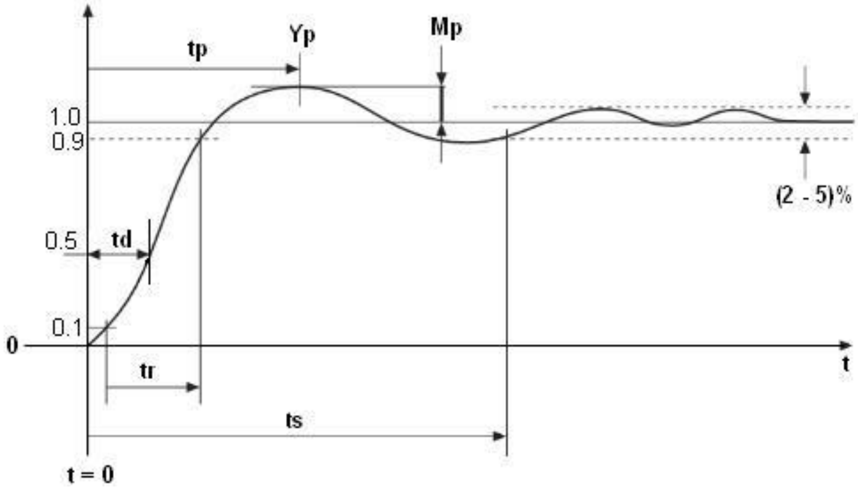
Rise Time (Tr): is the time required for the response to rise from 0 to 90% of the final value.

Settling Time (Ts): is the time required for the response to reach and stay within a specified tolerance band (2% or 5%) of its final value.

Peak Time (Tp): is the time required for the underdamped step response to reach the peak of time response (Yp) or the peak overshoot.

Percent Overshoot (OS%): is the normalized difference between the response peak value and the steady value This characteristic is not found in a first order system and found in higher one for the underdamped step response. It is defined as:

$$\text{Percent Overshoot (OS\%)} = \frac{Y_{max} - Y_{ss}}{Y_{ss}} \times 100\%$$



Philadelphia University

Electrical engineering Department

Control systems Laboratory

610416

Experiment Title:

Experiments number:

Date:

Student Name:

Student Number:

Supervisor Name: Eng.Esra'a Alghsoon

Introduction

Part 1:

Connect the modules that you need it in this experiment and follow the procedure steps on your manual to complete tables below:

Attenuator Position (K)	Error voltage

Construct graph by plotting Attenuator Position versus the Error voltage then write down your notes:

Notes :

1-

2-

Part 2:

Variations on the PID CONTROLLER Constants

• Carry out the circuit of figure 4.5.4

• Set the function generator with a square wave output with amplitude from -4 and +4 Volt and 0.1 Hz frequency.

• Apply one probe of the oscilloscope to the signal generator output

• Set the PID CONTROLLER to operate with the actions inserted contemporaneously

• Apply the second probe of the oscilloscope to terminal 23 and check the system response to the input stress.

• Change the weight of the three actions and check the system response to these variations

• Combine the PID CONTROLLER by removing one or more actions and observe how the systems responds to step stresses with P, I, PI Plot all responses .

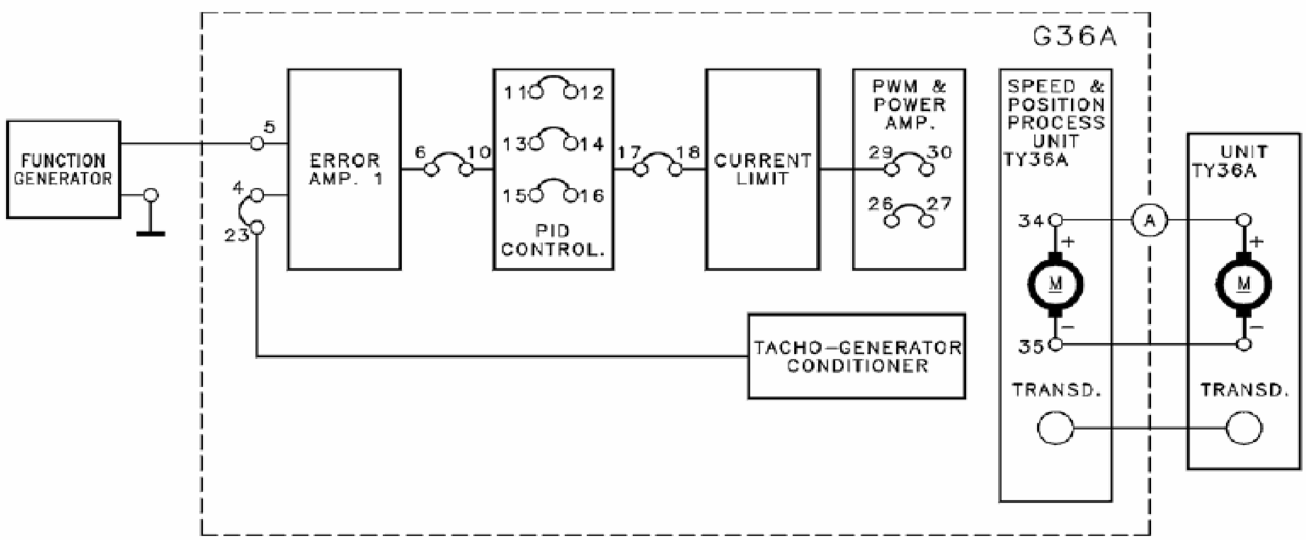


Fig. 4.5.4

Controller type	settings	TR	TS	OS
P	with high Kp			
	with law Kp			
I	with high Ki			
	with law Ki			
PI	with high Kp			
	with law Kp			
	with high Ki			
	with law Ki			

Down load your notes:

Conclusion:

Experiment 8

Dc servo motor system Matlab simulink

Philadelphia University

Electrical engineering Department

Control systems Laboratory

610416

Experiment Title:

Experiments number :

Date:

Student Name:

Student Number:

Supervisor Name: Eng.Esra'a Alghsoon

Build Simulink model on Matlab for Dc servo motor closed loop system

Introduction to MATLAB 7 for Engineers

William J. Palm III

Chapter 10

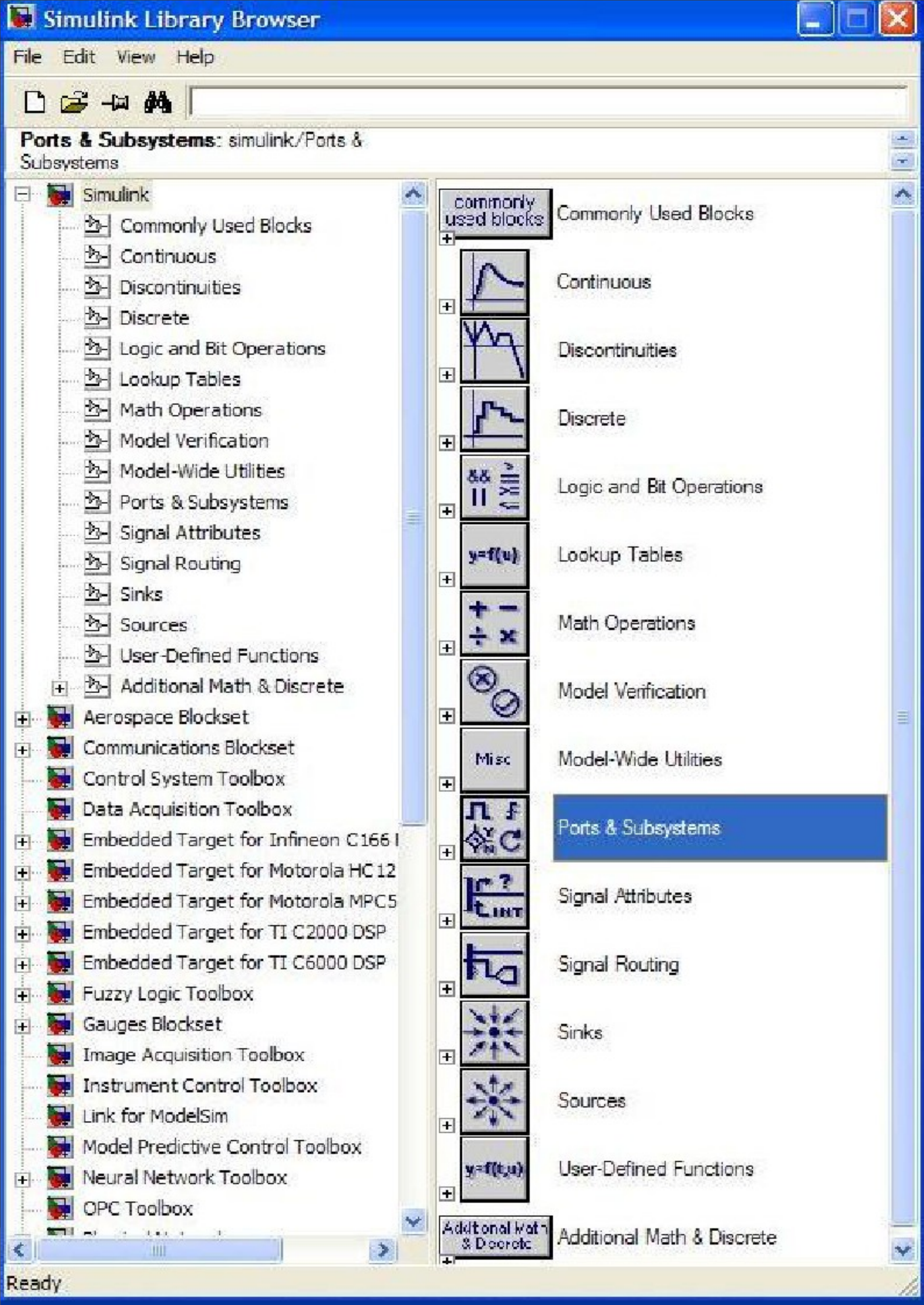
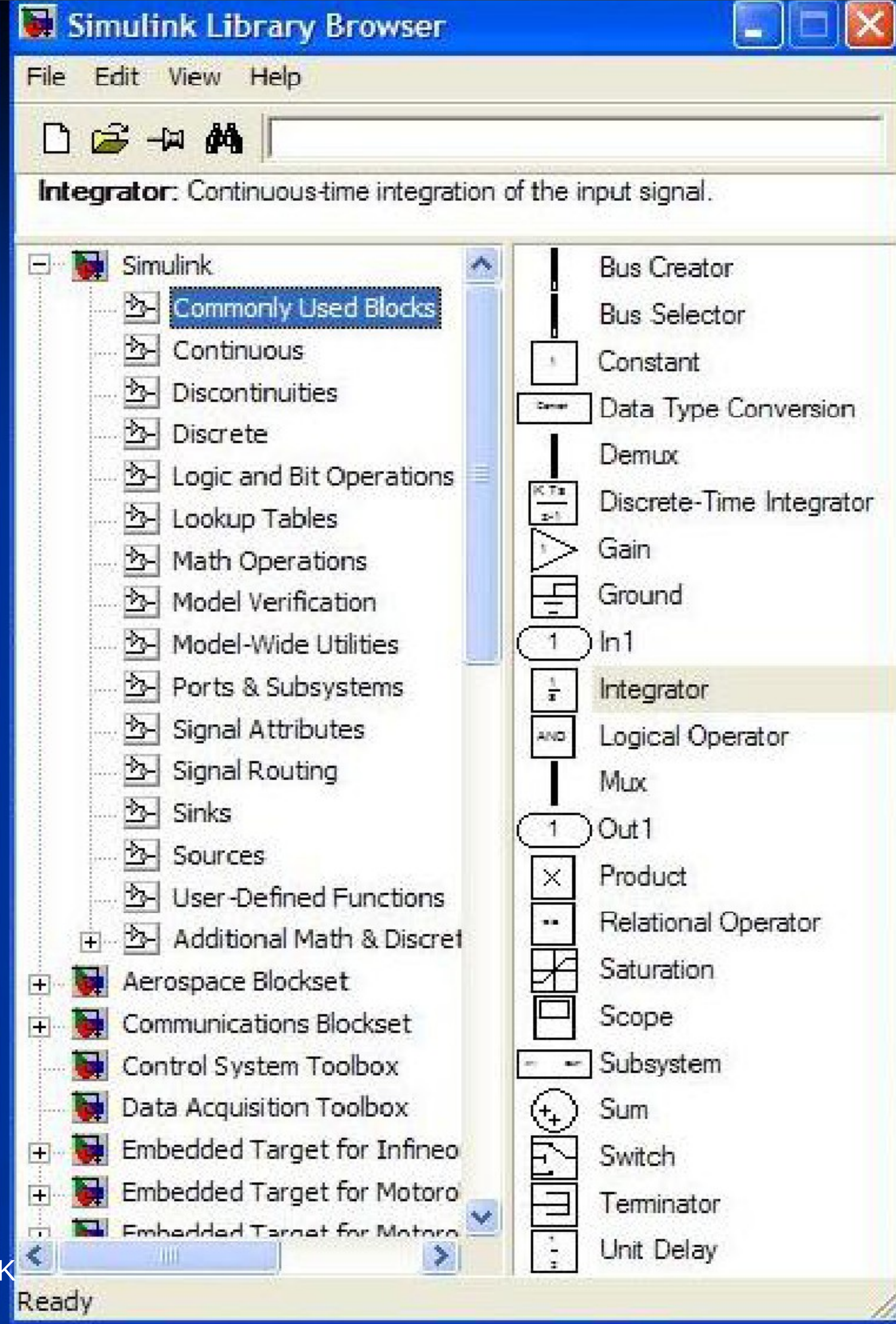
Introduction to MATLAB Simulink

Simulink® is MATLAB software for modeling, simulating, and analyzing dynamic systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate, i.e., have different parts that are sampled or updated at different rates.

SIMULINK is a MATLAB add-on for visually modeling dynamical systems. To get started with SIMULINK, choose File, New, Model.

Simulink is a platform for multidomain simulation and Model-Based Design for dynamic systems. It provides an interactive graphical environment and a customizable set of block libraries, and can be extended for specialized applications.

The Simulink library browser is shown in the next slide.

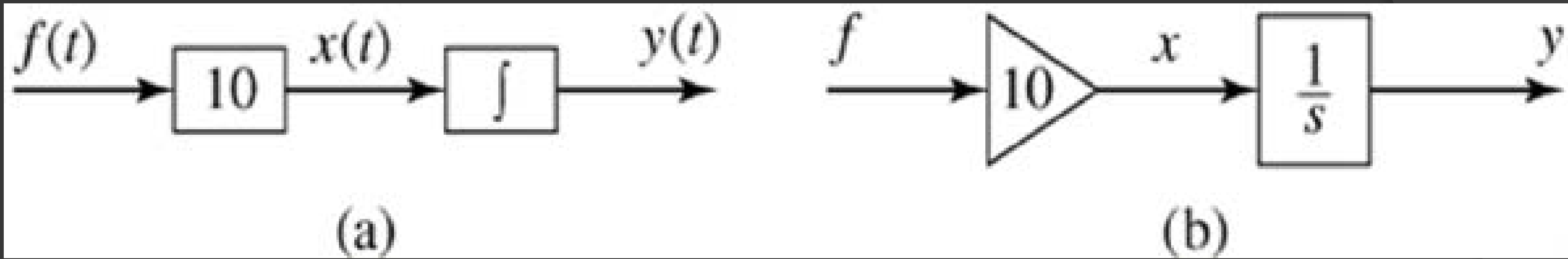

Simulink Library Browser
File Edit View Help
Ports & Subsystems: simulink/Ports & Subsystems
Simulink
Commonly Used Blocks
Continuous
Discontinuities
Discrete
Logic and Bit Operations
Lookup Tables
Math Operations
Model Verification
Model-Wide Utilities
Ports & Subsystems
Signal Attributes
Signal Routing
Sinks
Sources
User-Defined Functions
Additional Math & Discrete
Aerospace Blockset
Communications Blockset
Control System Toolbox
Data Acquisition Toolbox
Embedded Target for Infineon C166
Embedded Target for Motorola HC12
Embedded Target for Motorola MPC5
Embedded Target for TI C2000 DSP
Embedded Target for TI C6000 DSP
Fuzzy Logic Toolbox
Gauges Blockset
Image Acquisition Toolbox
Instrument Control Toolbox
Link for ModelSim
Model Predictive Control Toolbox
Neural Network Toolbox
OPC Toolbox
commonly used blocks
Commonly Used Blocks
Continuous
Discontinuities
Discrete
Logic and Bit Operations
y=f(u)
Lookup Tables
Math Operations
Model Verification
Misc
Model-Wide Utilities
Ports & Subsystems
Signal Attributes
Signal Routing
Sinks
Sources
y=f(t,u)
User-Defined Functions
Additional Math & Discrete
Additional Math & Discrete
Ready

Simulink Library Browser
File Edit View Help
Integrator: Continuous-time integration of the input signal.
Simulink
Commonly Used Blocks
Continuous
Discontinuities
Discrete
Logic and Bit Operations
Lookup Tables
Math Operations
Model Verification
Model-Wide Utilities
Ports & Subsystems
Signal Attributes
Signal Routing
Sinks
Sources
User-Defined Functions
Additional Math & Discret
Aerospace Blockset
Communications Blockset
Control System Toolbox
Data Acquisition Toolbox
Embedded Target for Infineo
Embedded Target for Motoro
Bus Creator
Bus Selector
Constant
Data Type Conversion
Demux
Discrete-Time Integrator
Gain
Ground
In1
Integrator
Logical Operator
Mux
Out1
Product
Relational Operator
Saturation
Scope
Subsystem
Sum
Switch
Terminator
Unit Delay
Ready

Features of MATLAB and Simulink

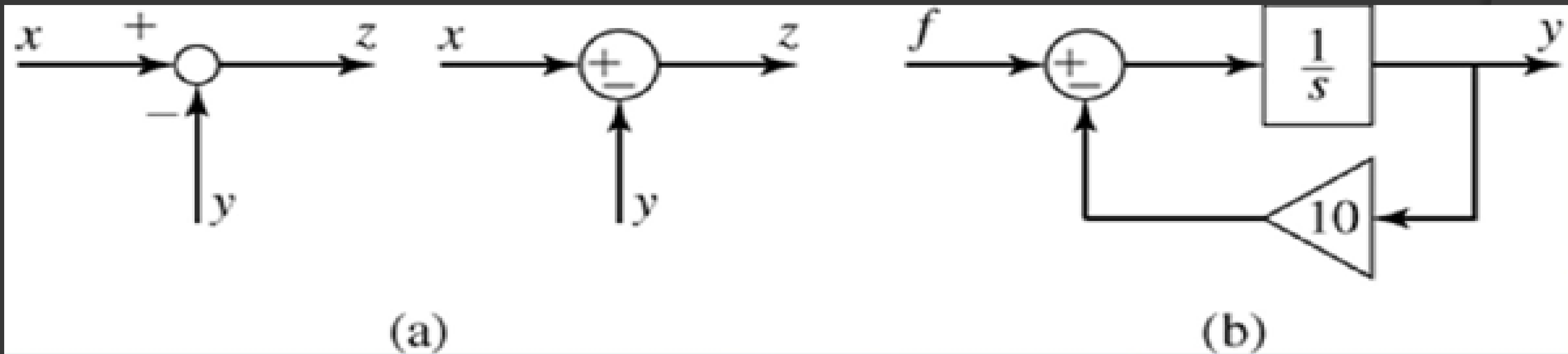
- ☐ Matlab (*.m):
  - ☐ Only text code (*Not easy to model complicated systems*)
  - ☐ Easy to edit figures
- ☐ Simulink (*.mdl):
  - ☐ Schematic (*Easy to model complicated systems*)
  - ☐ Not easy to change parameters
  - ☐ Can not edit figures
- ☐ Matlab (*.m) + Simulink (*.mdl): *Best choice*
  - ☐ Schematic: Simulink
  - ☐ Easy to change parameters: Matlab (m file for parameter initialization)
  - ☐ Edit figures: Simulink ⇒ ("To Workspace ")

  ⇒ Matlab (m file for plot)

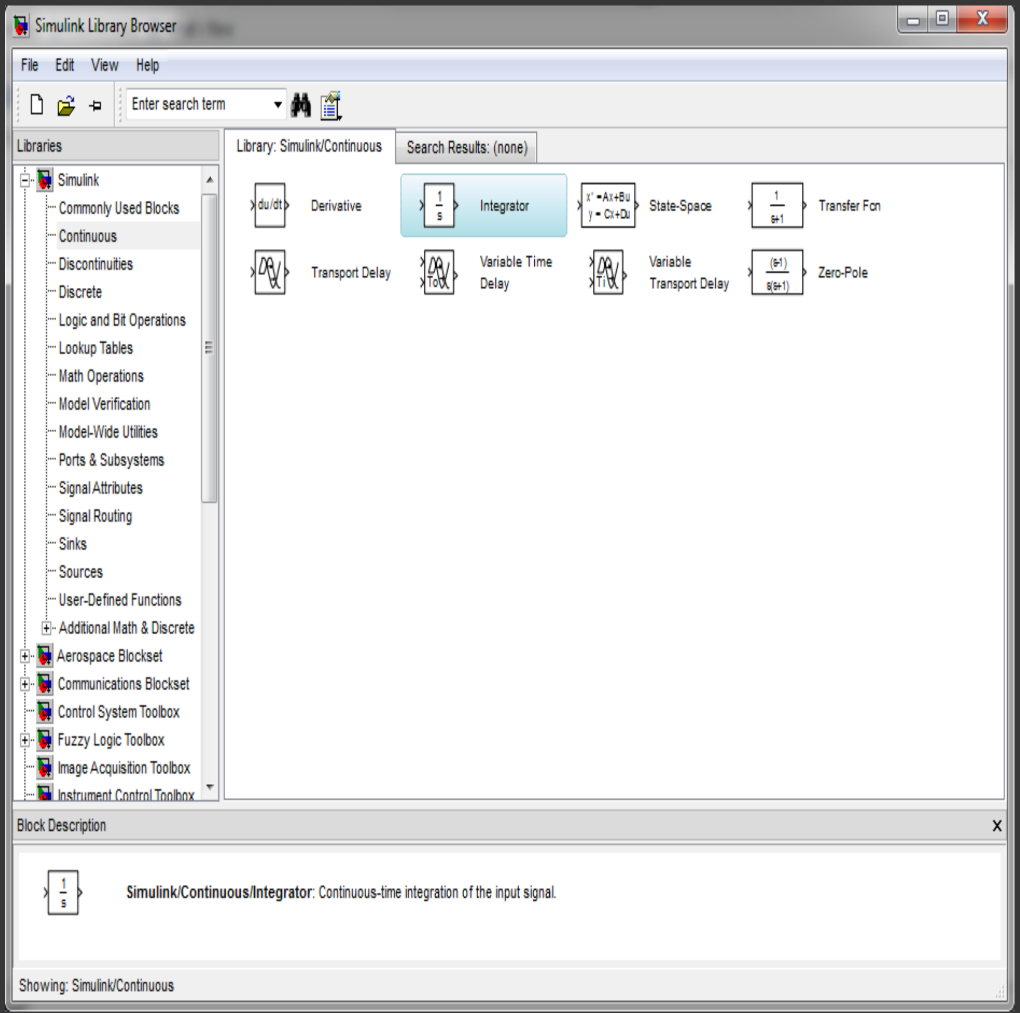
Simulation diagrams for $y' = 10 f(t)$.



a- The summer element. b- Simulation diagram for $y' = f(t) - 10y$.

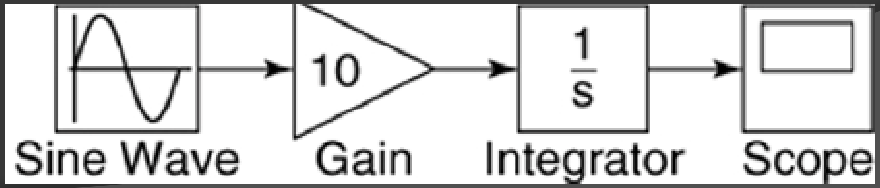


Simulink Library Browser



Simulink model for

$$y' = 10 \sin t$$



Note that blocks have a Block Parameters window that opens when you double-click on the block.
This window contains several items, the number and nature of which depend on the specific type of block.
In general, you can use the default values of these parameters, except where we have explicitly indicated that they should be changed.
You can always click on Help within the Block Parameters window to obtain more information.

Note that most blocks have default labels.
You can edit text associated with a block by clicking on the text and making the changes.
You can save the Simulink model as an `.mdl` file by selecting Save from the File menu in Simulink.
The model file can then be reloaded at a later time.
You can also print the diagram by selecting Print on the File menu.

Double-click on the To Workspace block. You can specify any variable name you want as the output; the default is `simout`. Change its name to `y`.

The output variable `y` will have as many rows as there are simulation time steps, and as many columns as there are inputs to the block.

The second column in our simulation will be time, because of the way we have connected the Clock to the second input port of the Mux.

Specify the Save format as Array. Use the default values for the other parameters (these should be `inf`, `1`, and `-1` for Maximum number of rows, Decimation, and Sample time, respectively). Click on OK.

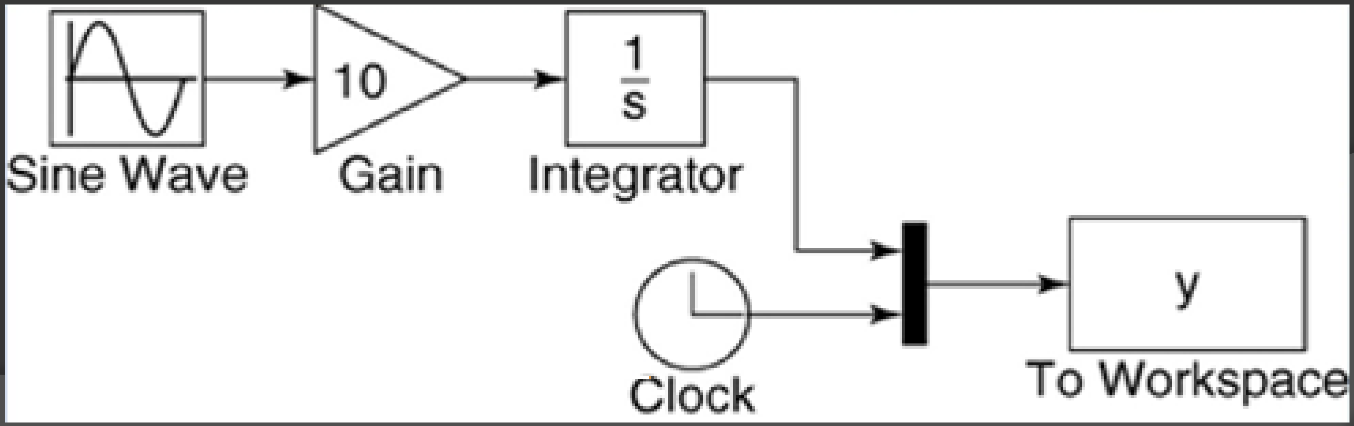
Simulink can be **configured** to put the **time** variable **`tout`** into the MATLAB **workspace** automatically when you are using the **To Workspace** block.

This is done with the Data I/O tab under Configuration Parameters on the Simulation menu.

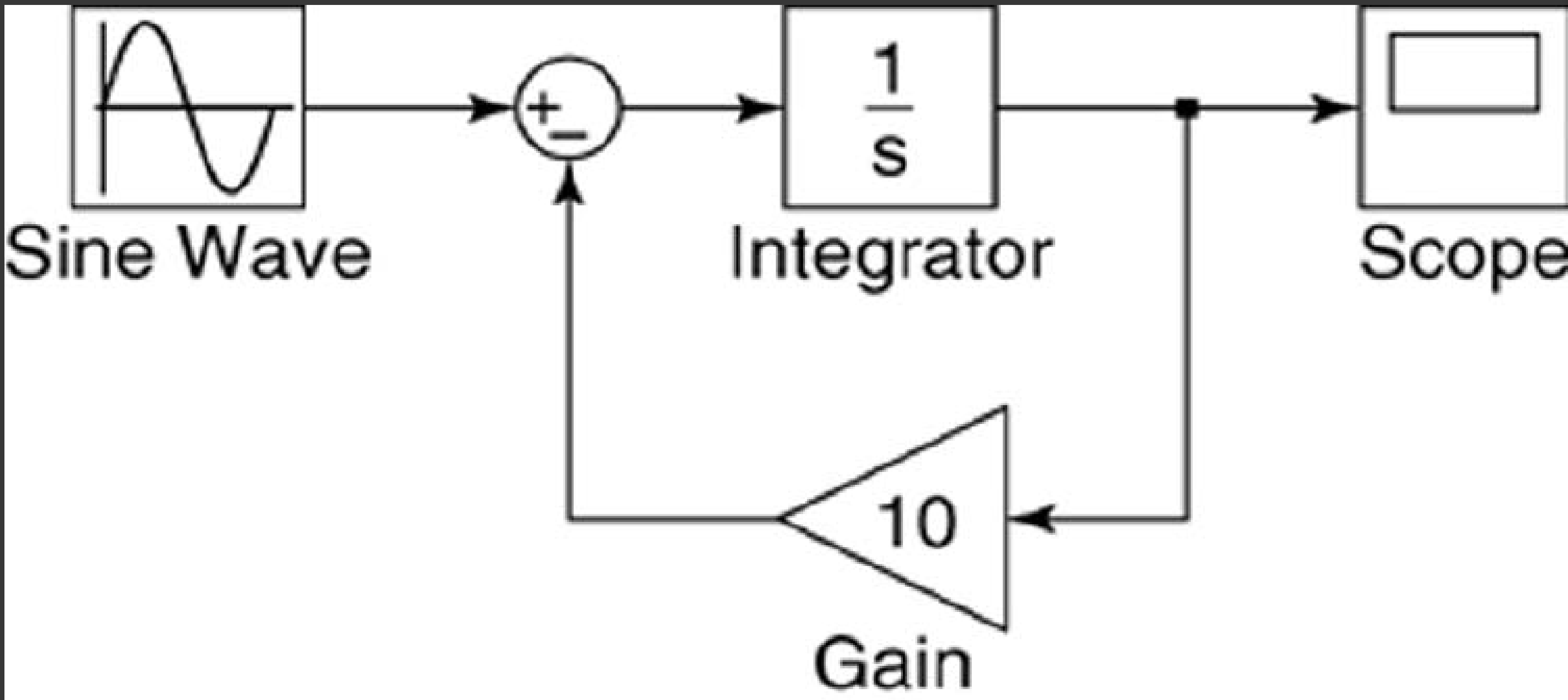
The alternative is to use the Clock block to put `tout` into the workspace.

The Clock block has one parameter, Decimation. If this parameter is set to 1, the Clock block will output the time every time step; if set to 10 ***for example*****, the block will output every 10 time steps, and so on.**

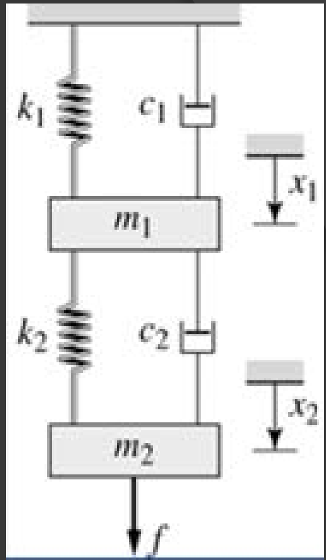
Simulink model using the Clock and To Workspace blocks.



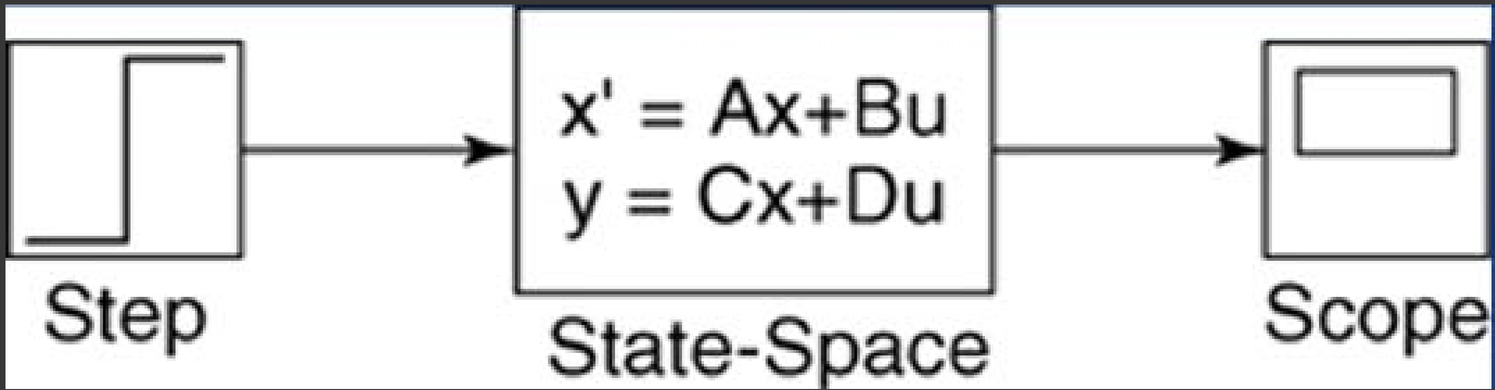
Simulink model for $y' = -10y + f(t)$.



A vibrating system has two masses and its state-space model is given.

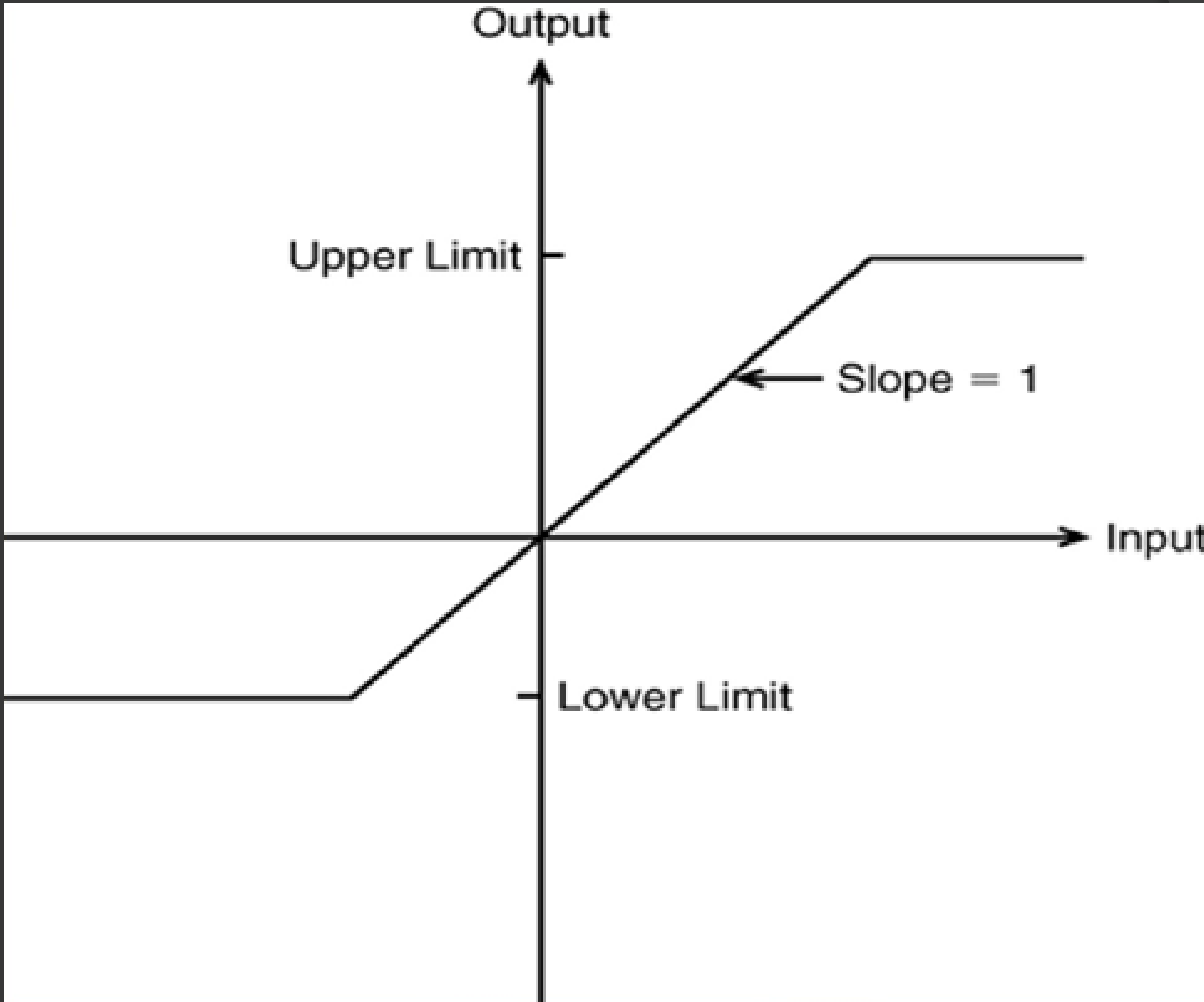


The following is a Simulink model for the system with State-Space block and Step block as input:



When you are connecting inputs to the State-Space block, care must be taken to connect them in the proper order. Similar care must be taken when connecting the block's outputs to another block.

The saturation nonlinearity.



Example 1

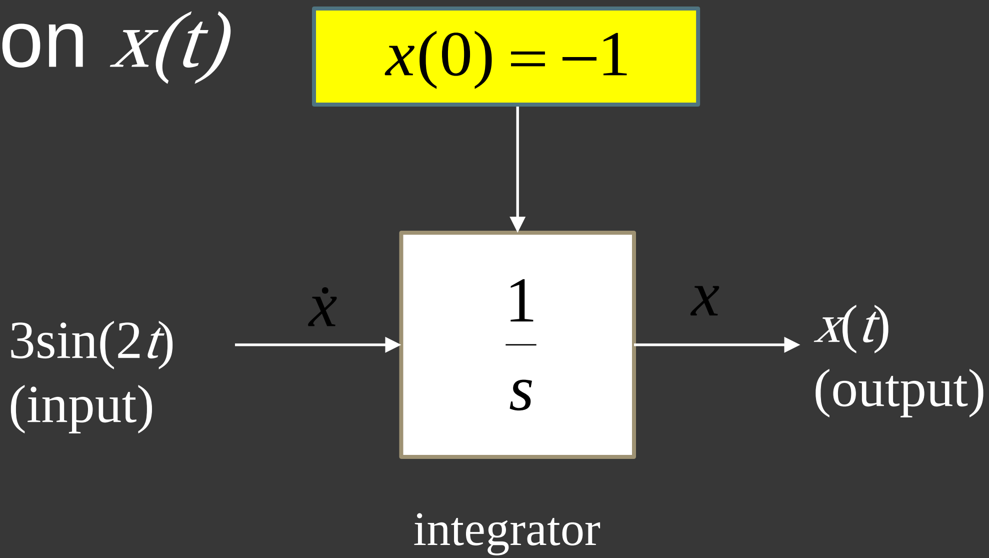
- Build a Simulink model that solves the differential equation

$$\dot{x} = 3\sin(2t)$$

- Initial condition $x(0) = -1.$
- First, sketch a simulation diagram of this mathematical model (equation)

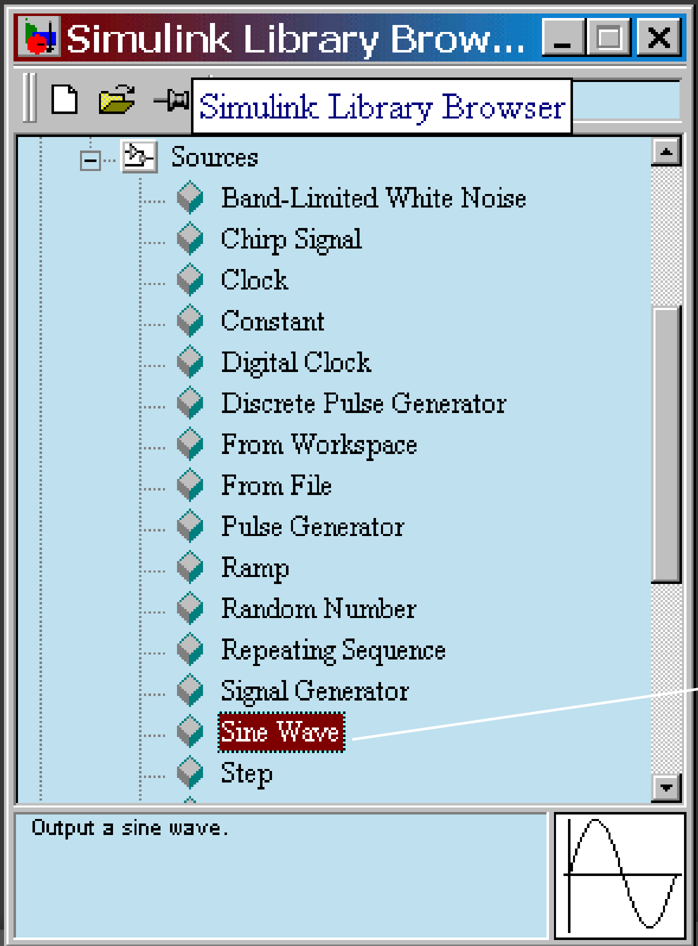
Simulation diagram

- Input is the forcing function $3\sin(2t)$
- Output is the solution of the differential equation $x(t)$

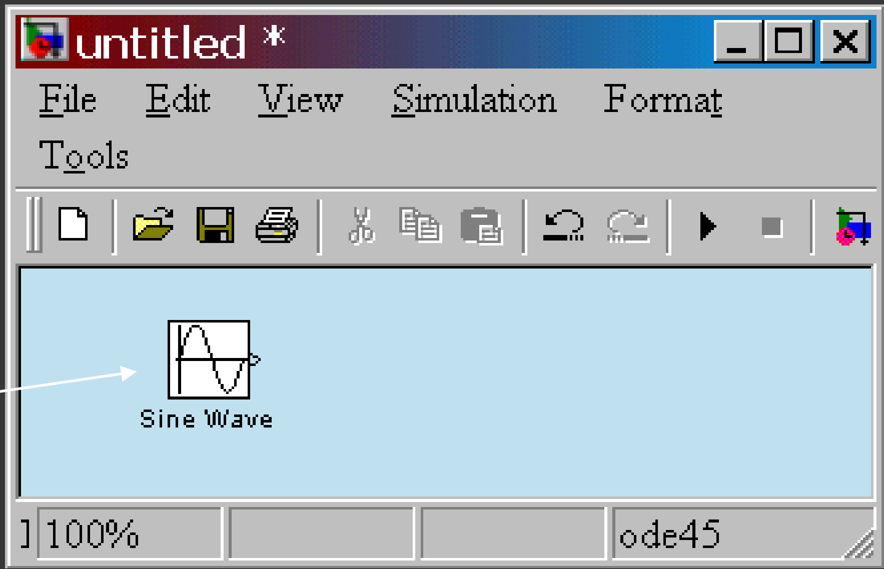


- Now build this model in Simulink

Select an input block

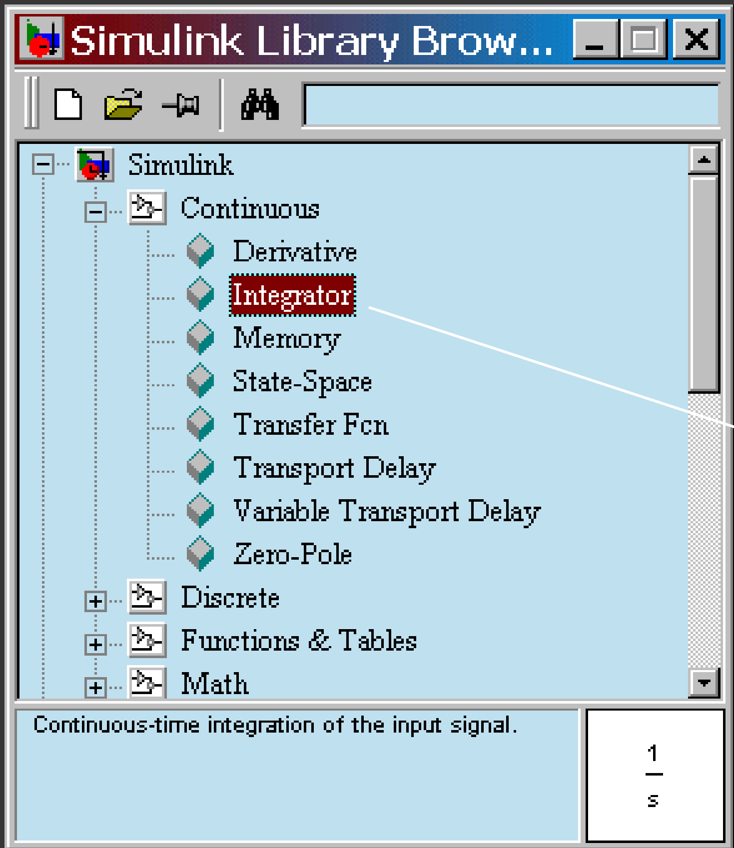


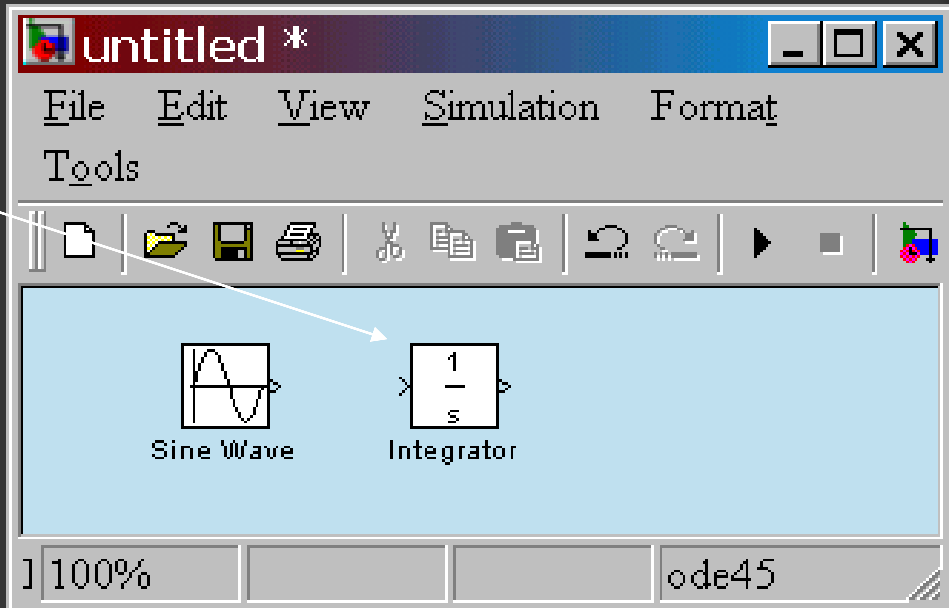
Drag a *Sine Wave* block from the *Sources* library to the model window



Select an operator block

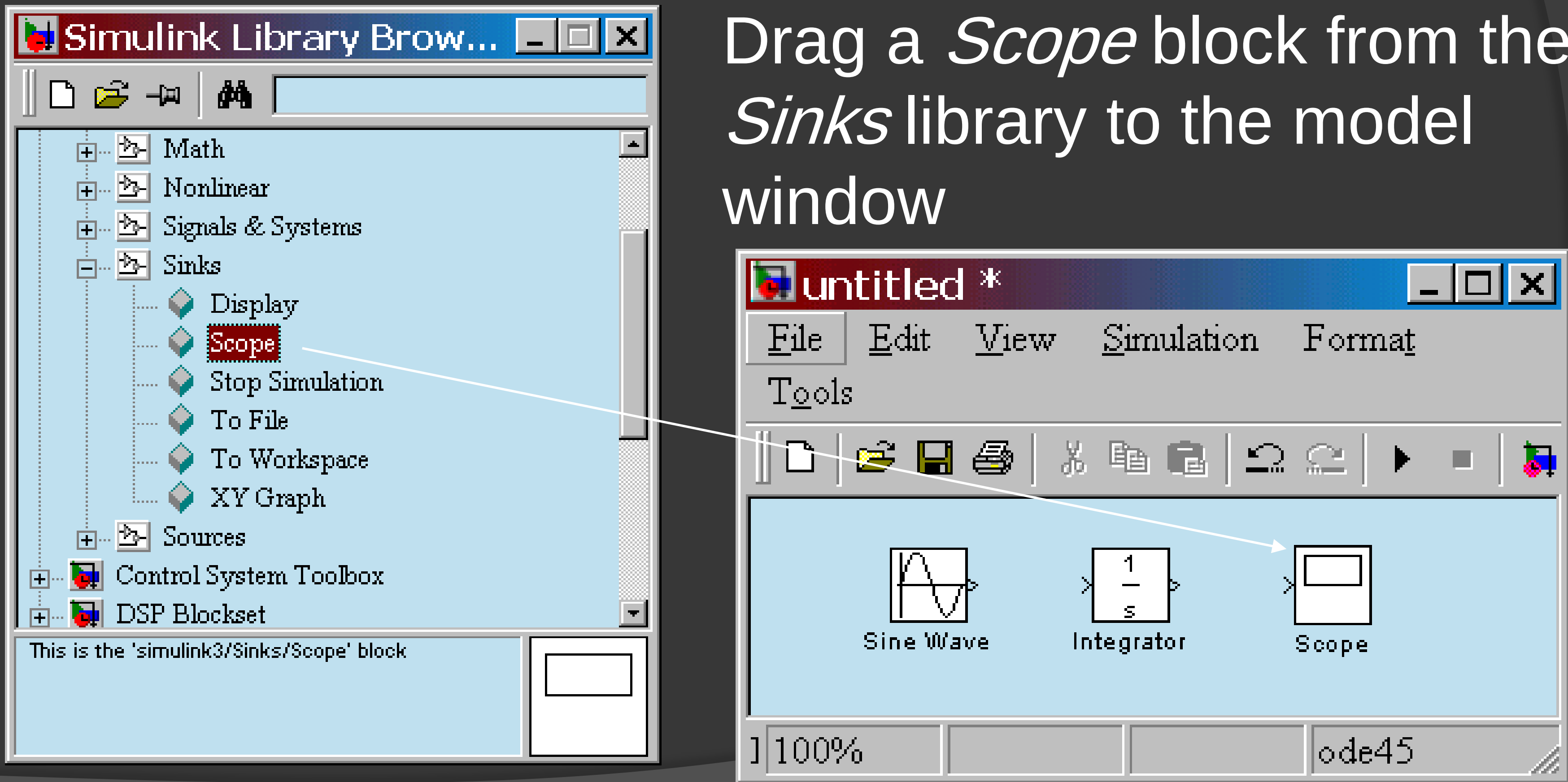
Drag an *Integrator* block from the *Continuous* library to the model window





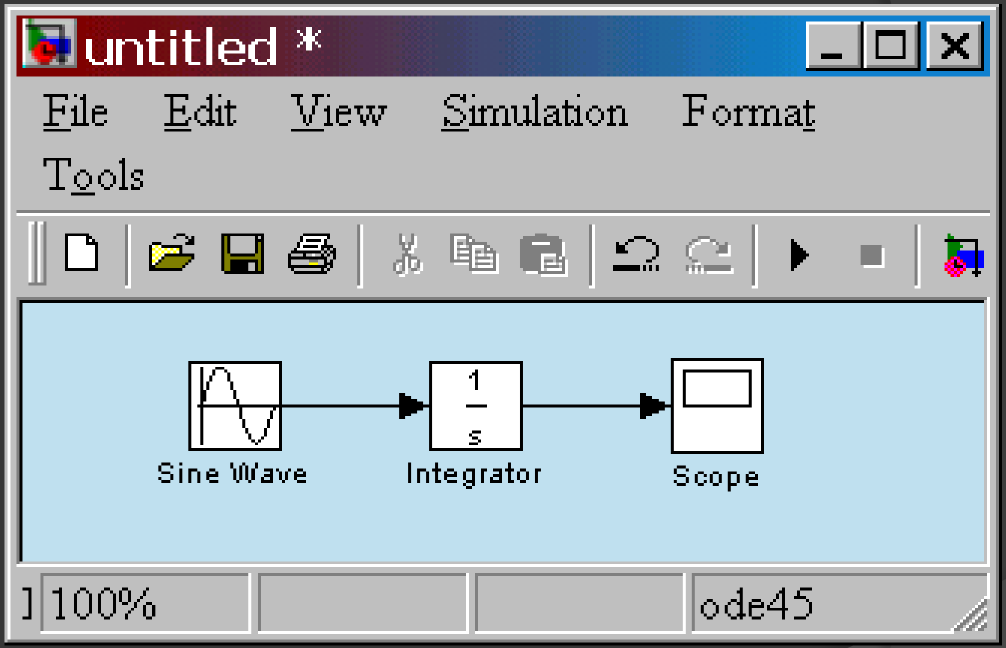
Select an output block

Drag a *Scope* block from the *Sinks* library to the model window



Connect blocks with signals

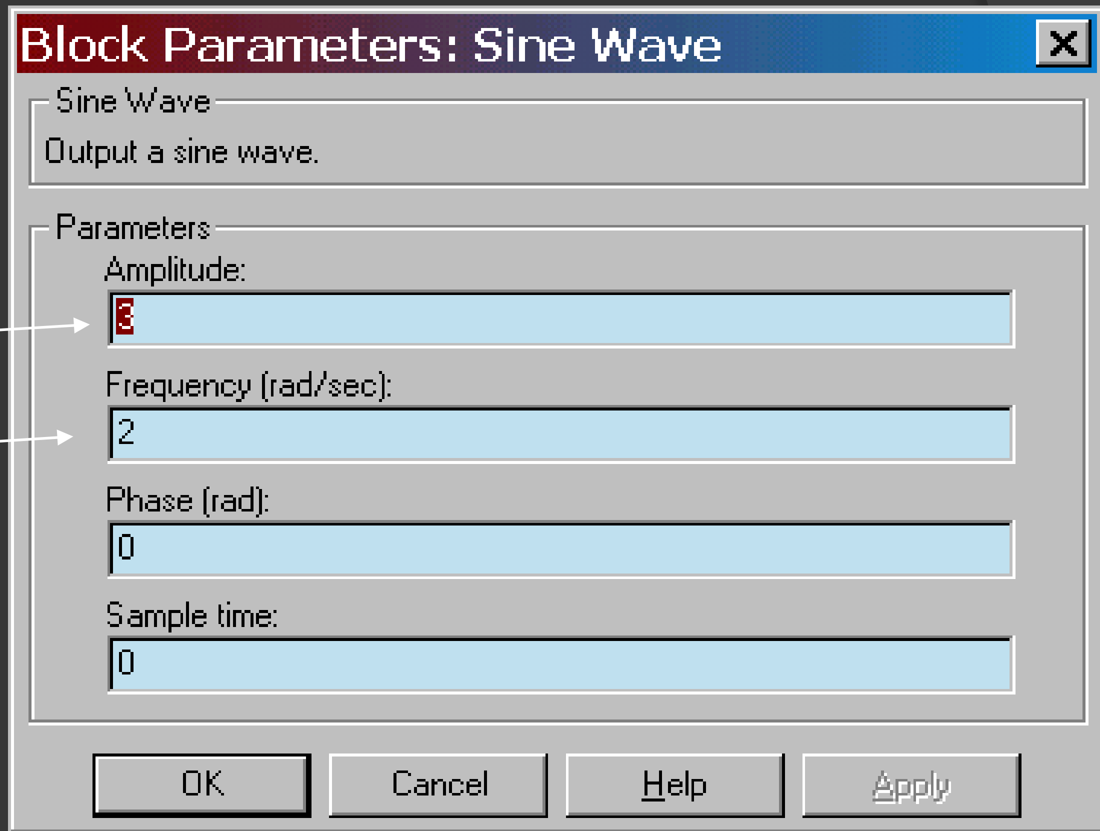
- Place your cursor on the output port (>) of the *Sine Wave* block
- Drag from the *Sine Wave* **output** to the *Integrator* **input**
- Drag from the *Integrator* **output** to the *Scope* **input**



Arrows indicate the direction of the signal flow.

Select simulation parameters

Double-click on the *Sine Wave* block to set amplitude = 3 and freq = 2.

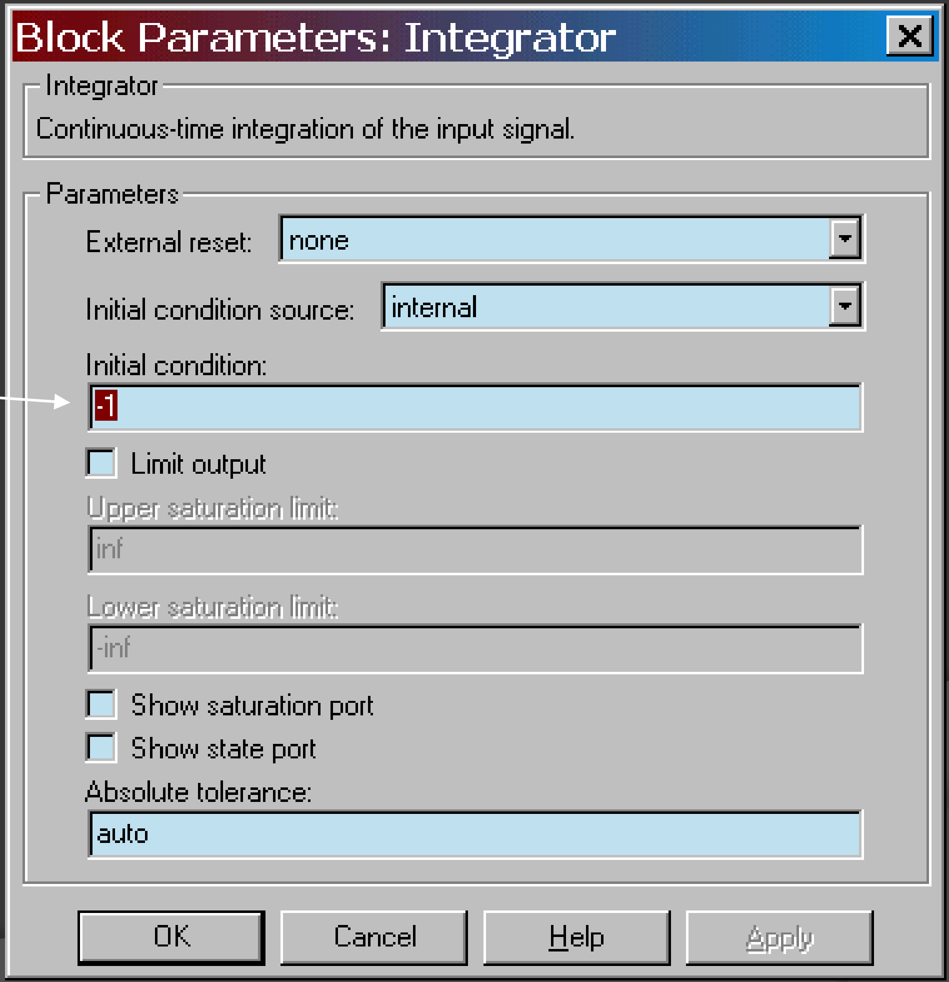


This produces the desired input of $3\sin(2t)$

Select simulation parameters

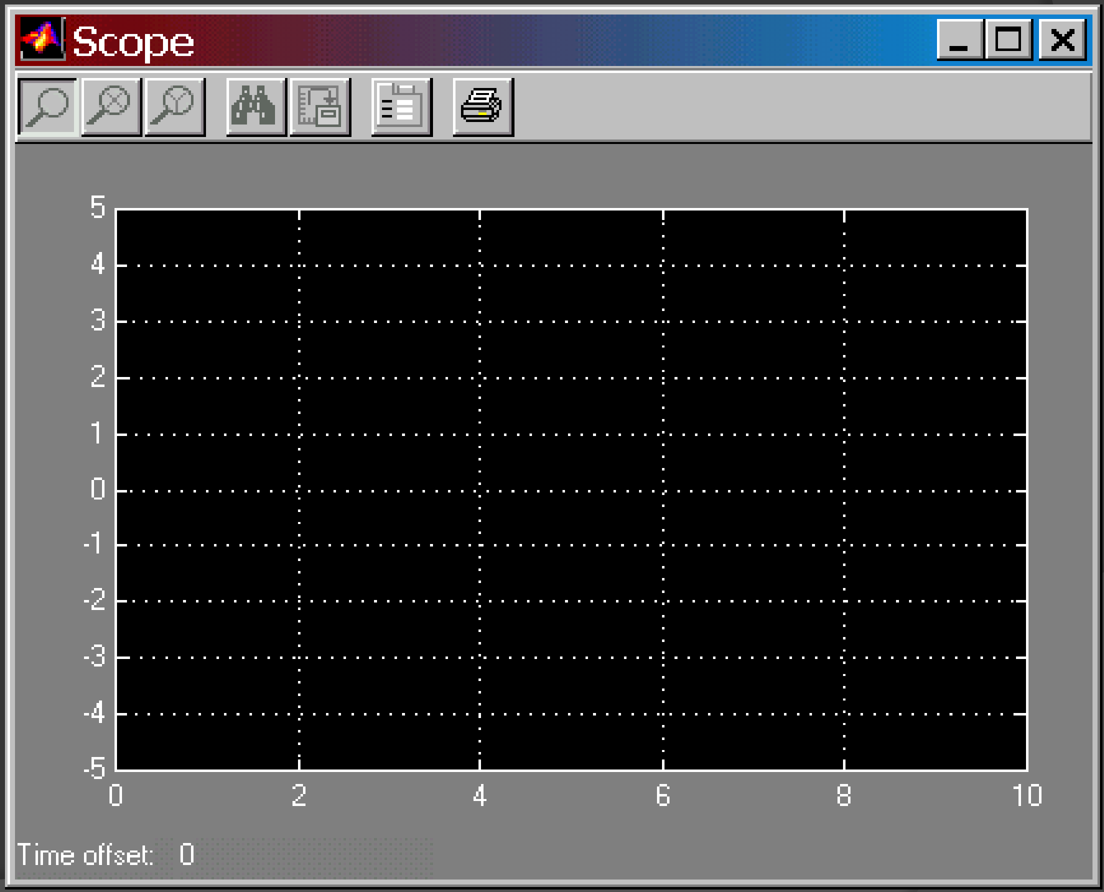
Double-click on the *Integrator* block to set initial condition = -1.

This sets our IC $x(0) = -1$.



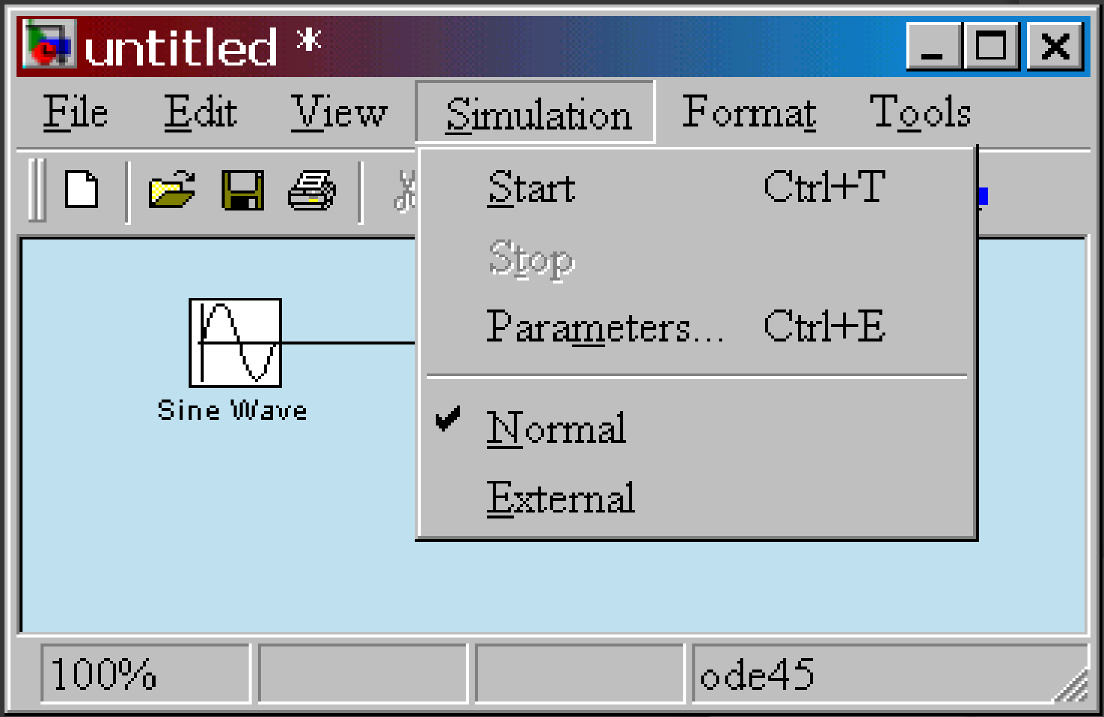
Select simulation parameters

Double-click on the *Scope* to view the simulation results



Run the simulation

In the model window, from the *Simulation* pull-down menu, select *Start*



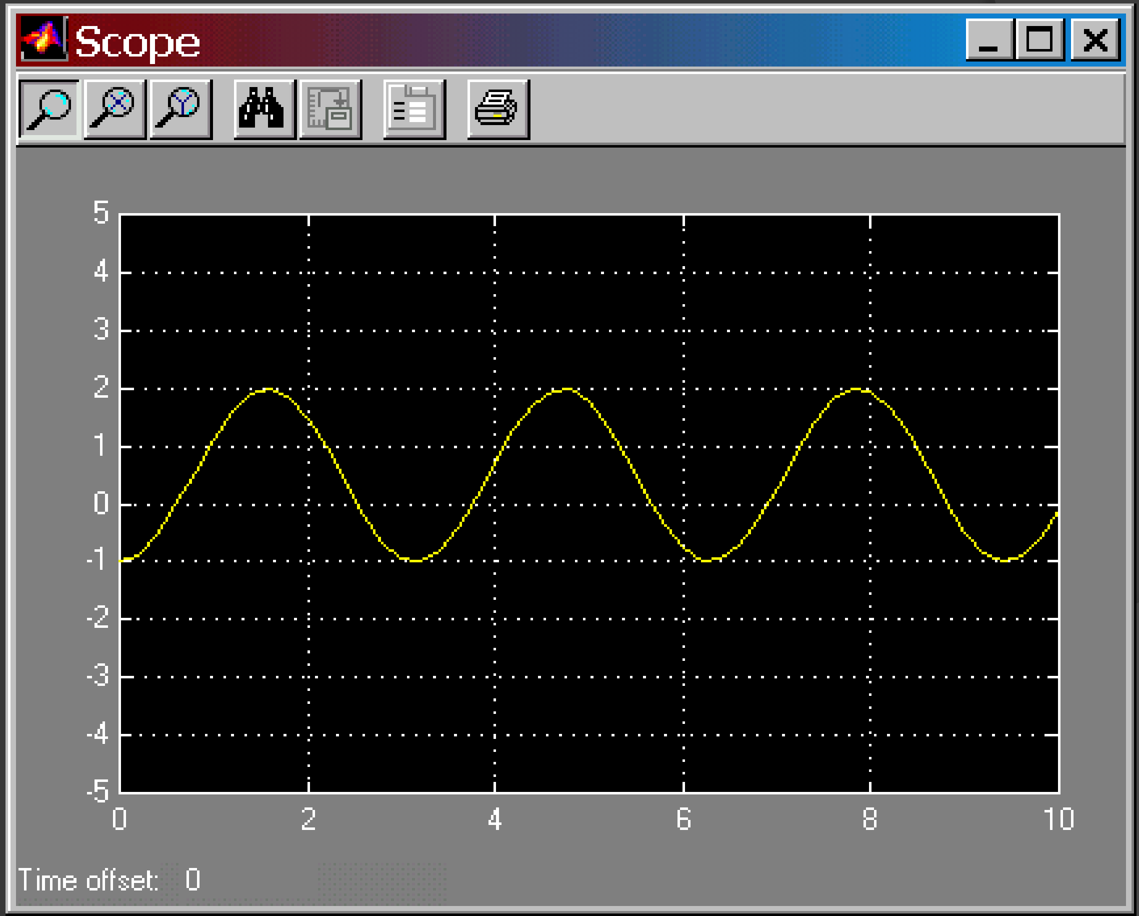
View the output $x(t)$ in the *Scope* window.

Simulation results

To verify that this plot represents the solution to the problem, solve the equation analytically.

The analytical result, matches the plot (the simulation result) exactly.

$$x(t) = \frac{1}{2} - \frac{3}{2}\cos\left(2t\right)$$



Example 2

- Build a Simulink model that solves the following differential equation
  - 2nd-order mass-spring-damper system
  - input $f(t)$ is a step with magnitude 3
  - parameters: $m = 0.25$, $c = 0.5$, $k = 1$

$$m\ddot{x} + c\dot{x} + kx = f(t)$$

Create the simulation diagram

- On the following slides:
  - The simulation diagram for solving the ODE is created step by step.
  - After each step, elements are added to the Simulink model.

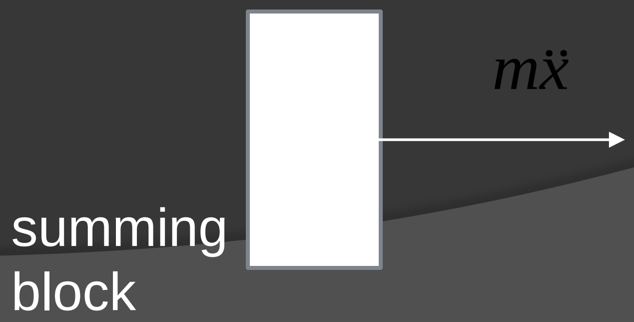
$$m\ddot{x} + c\dot{x} + kx = f(t)$$

(continue)

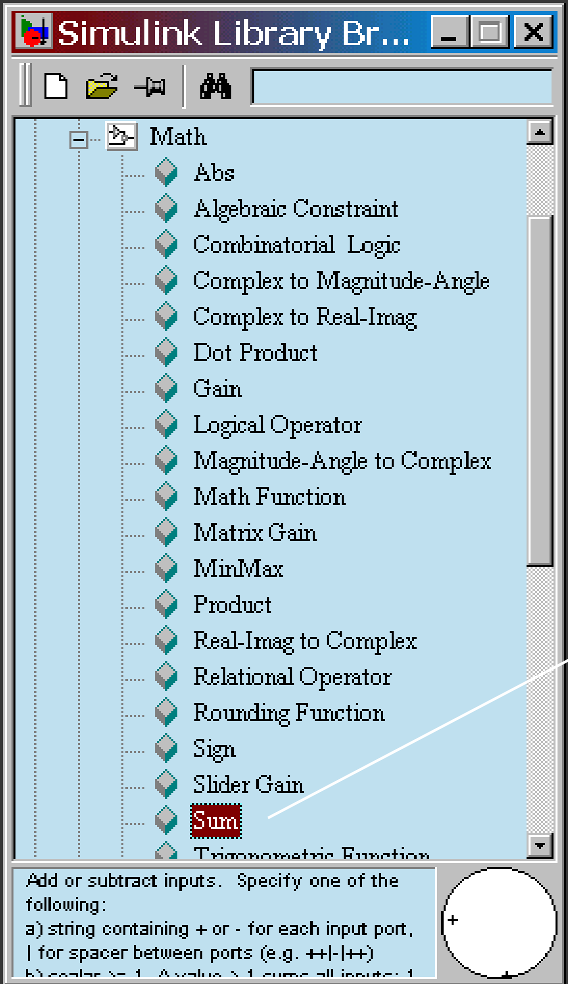
- First, solve for the term with highest-order derivative

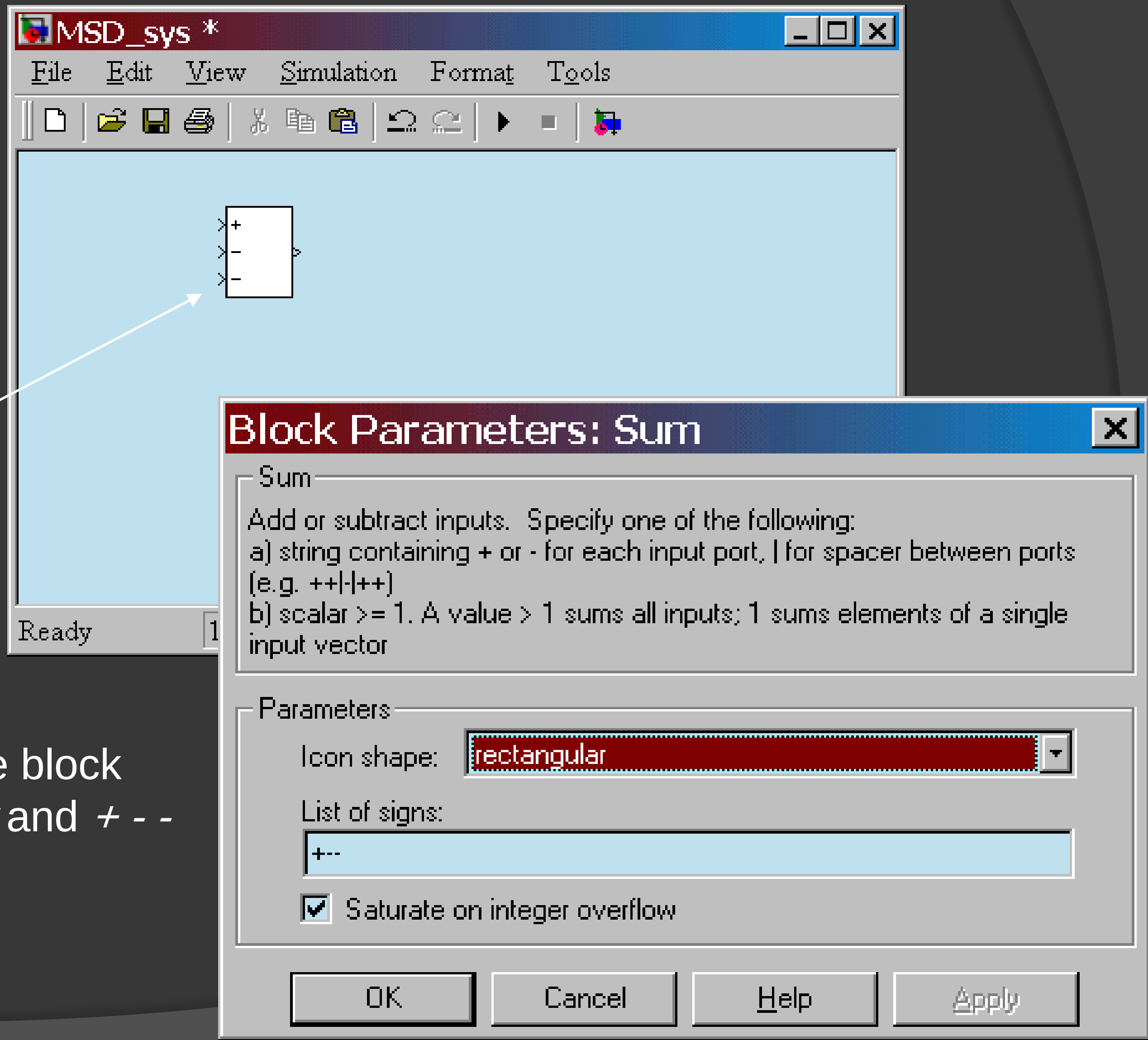
$$m\ddot{x} = f(t) - c\dot{x} - kx$$

- Make the left-hand side of this equation the output of a summing block



Drag a *Sum* block from the *Math* library

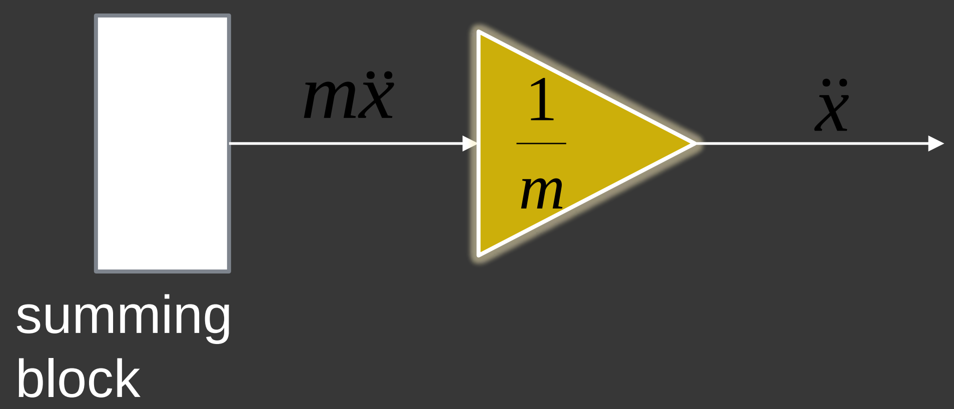




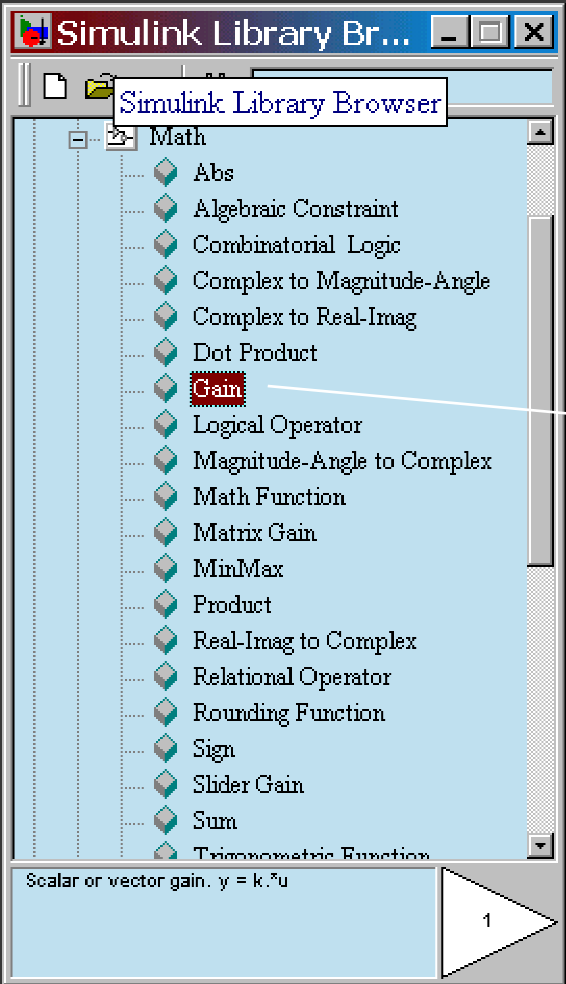
Double-click to change the block parameters to *rectangular* and *+ - -*

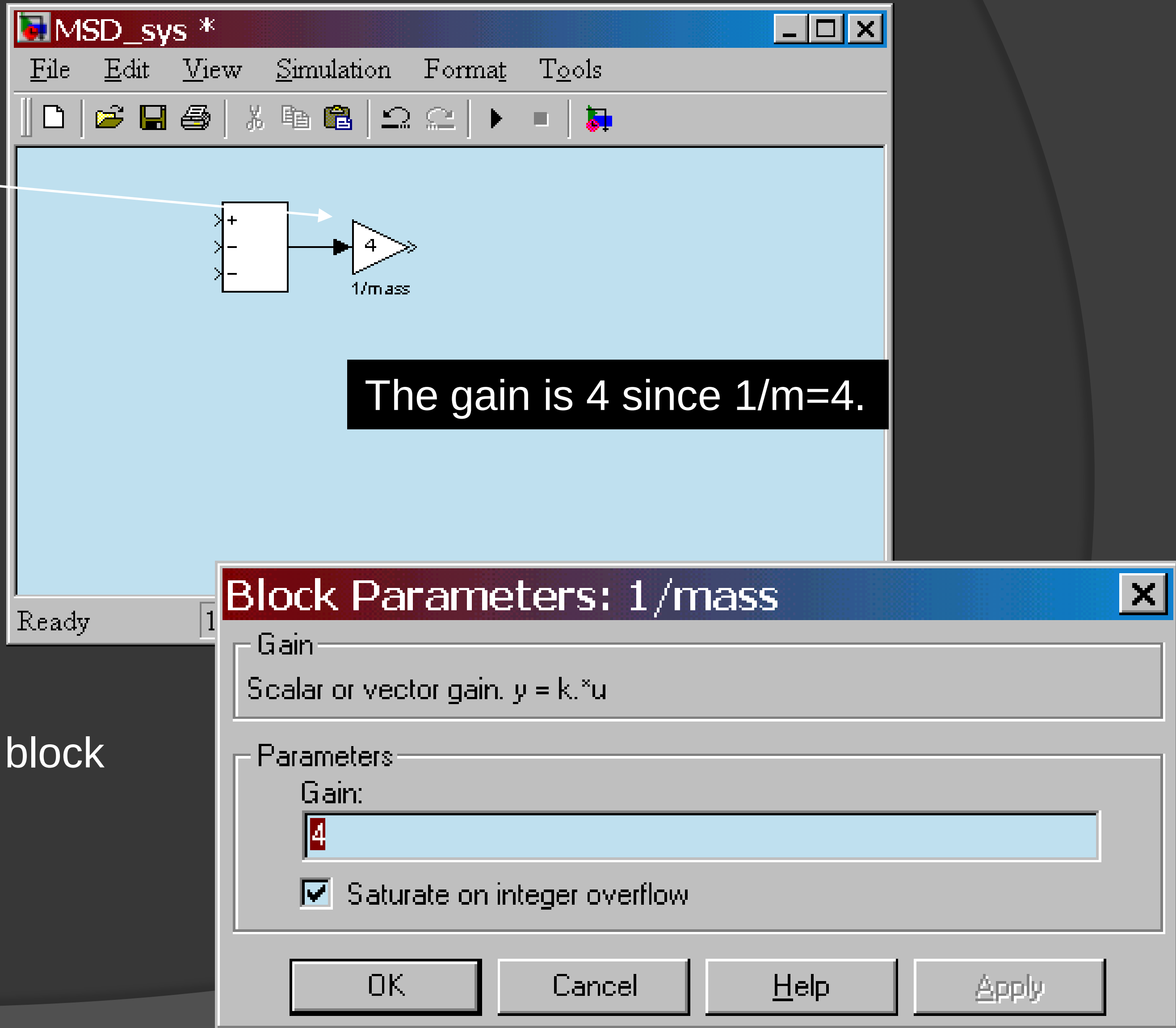
(continue)

- Add a gain (multiplier) block to eliminate the coefficient and produce the highest-derivative alone



Drag a *Gain* block from the *Math* library

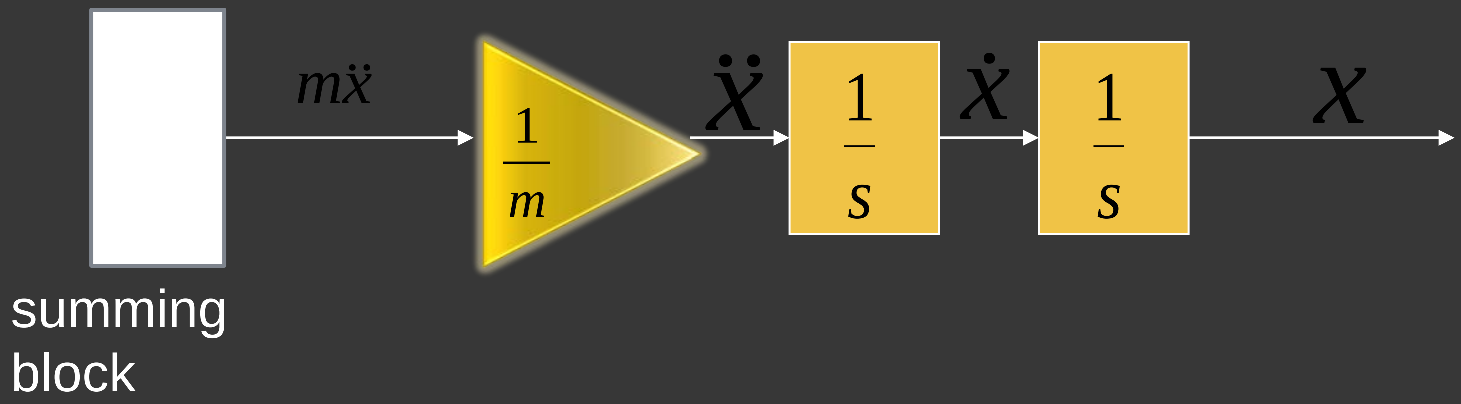




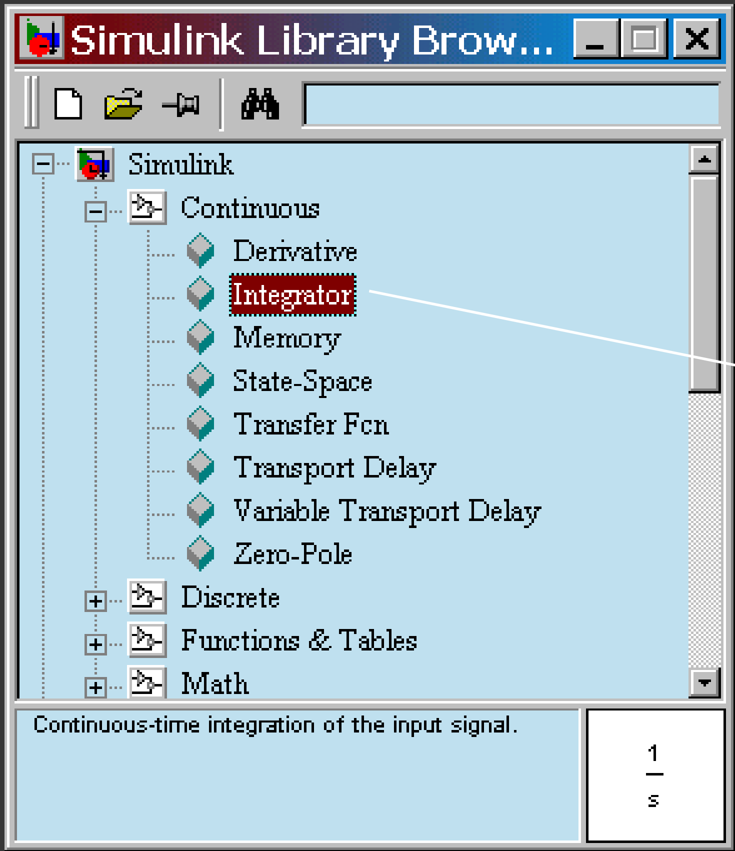
Double-click to change the block parameters.
Add a title.

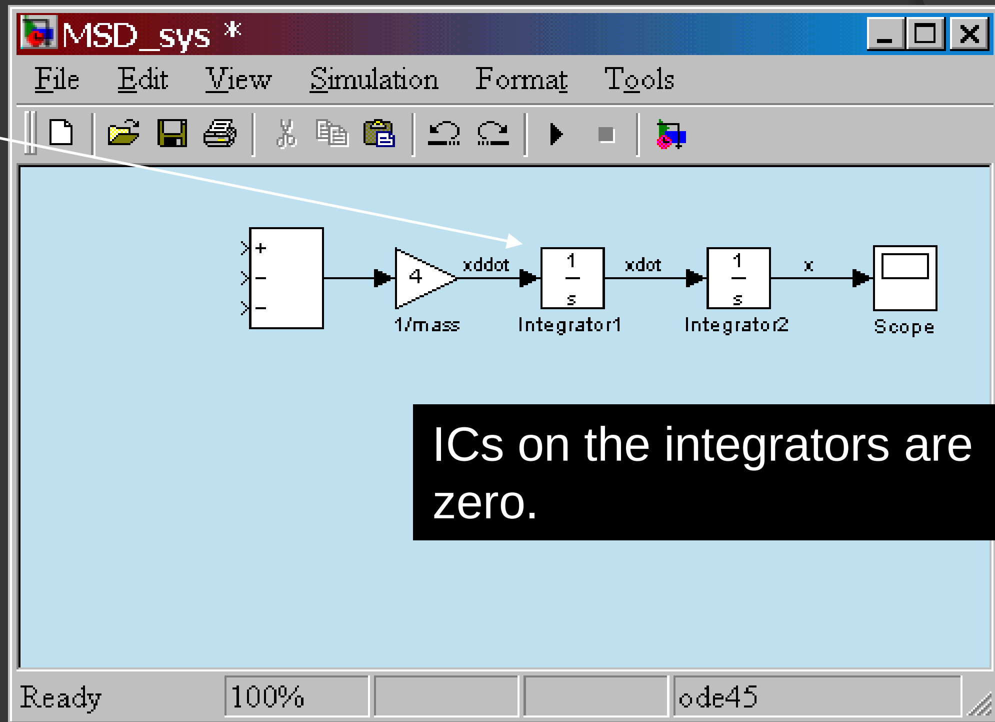
(continue)

- Add integrators to obtain the desired output variable



Drag *Integrator* blocks from the *Continuous* library



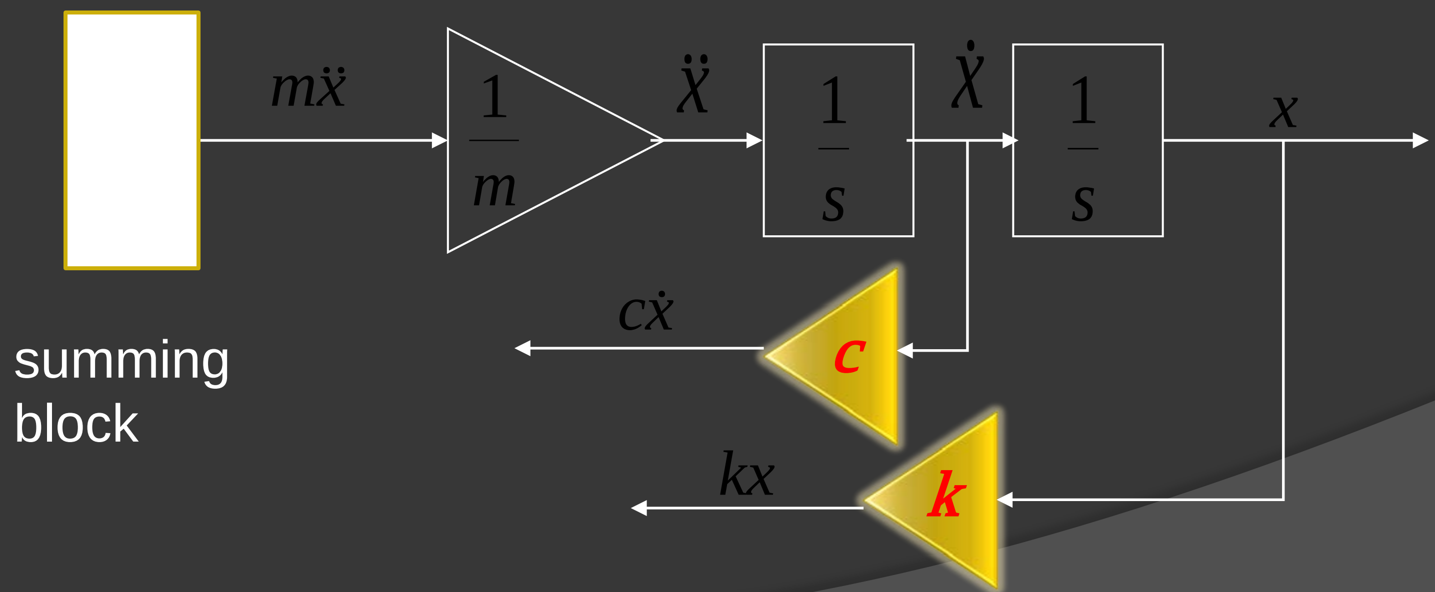


ICs on the integrators are zero.

Add a scope from the *Sinks* library.
Connect output ports to input ports.
Label the signals by double-clicking on the leader line.

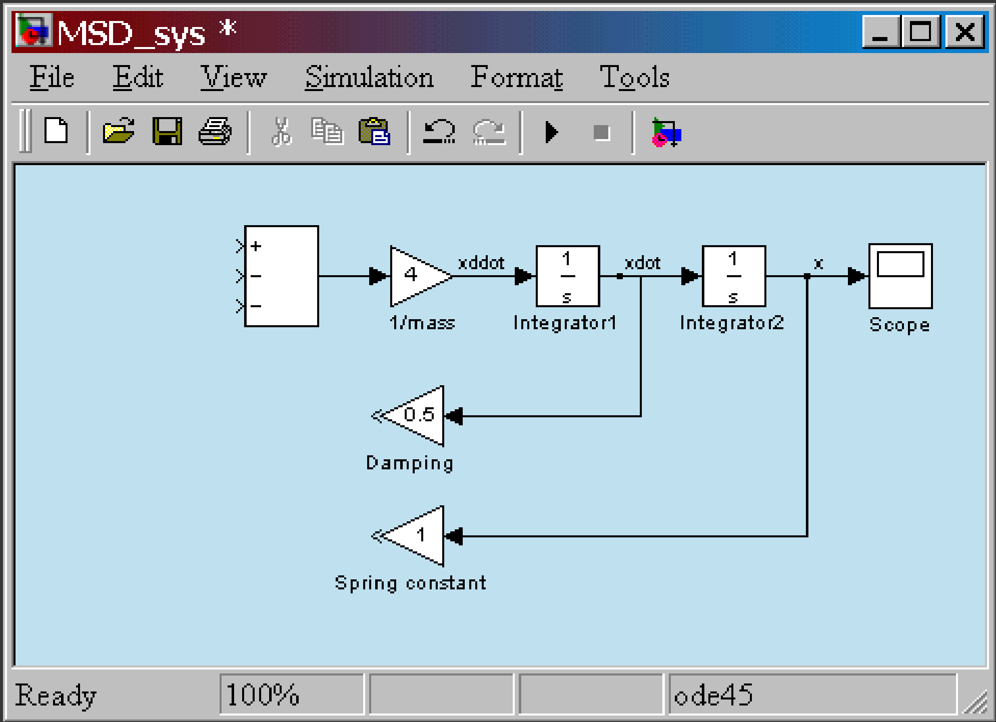
(continue)

- Connect to the integrated signals with gain blocks to create the terms on the right-hand side of the EOM

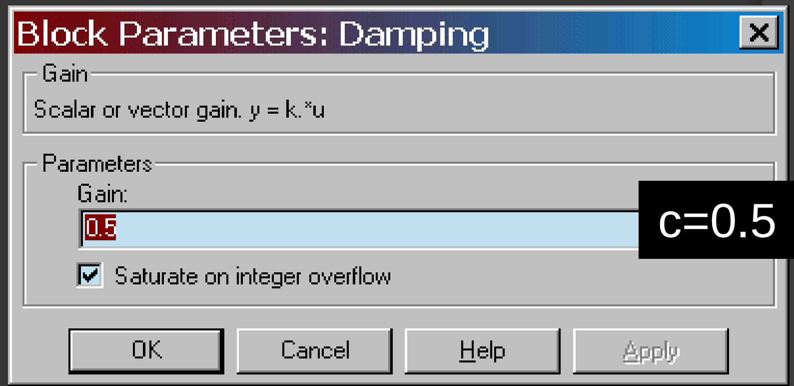


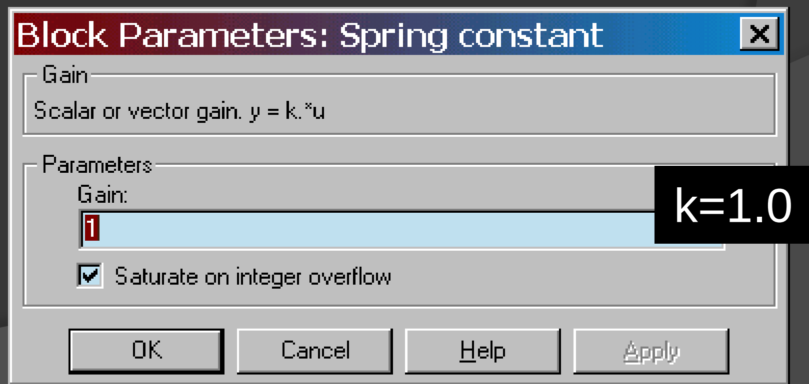
Drag new *Gain* blocks from the *Math* library

To flip the gain block, select it and choose *Flip Block* in the *Format* pull-down menu.



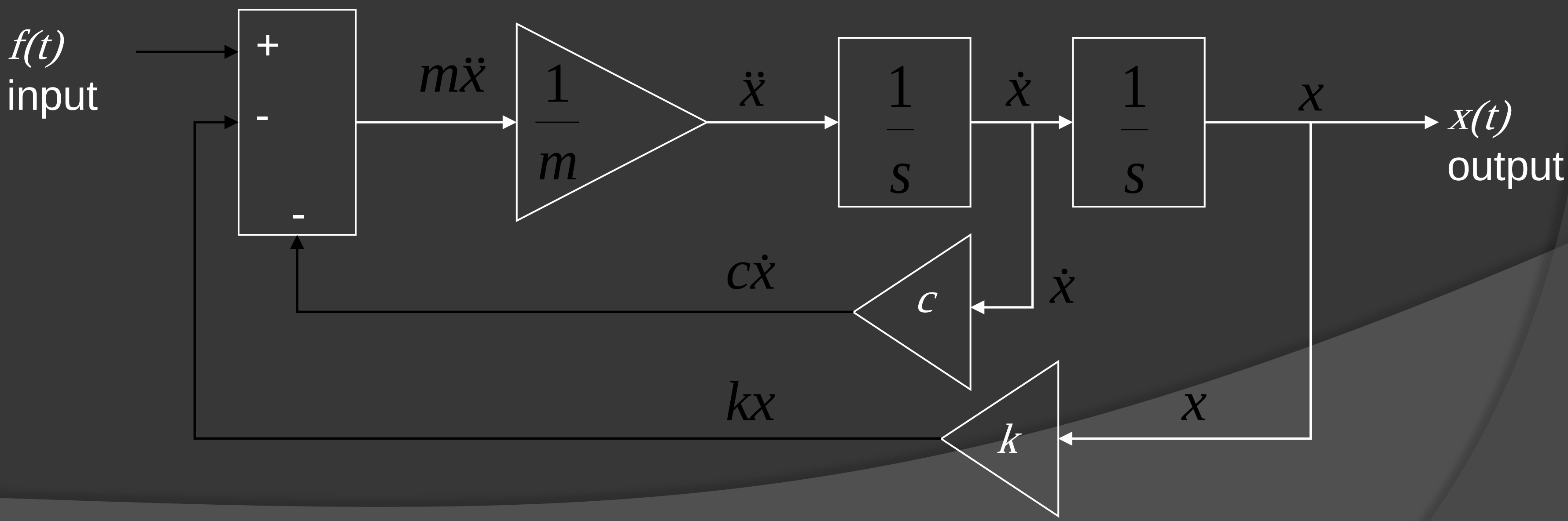
- Double-click on gain blocks to set parameters
- Connect from the gain block input backwards up to the branch point.
- Re-title the gain blocks.

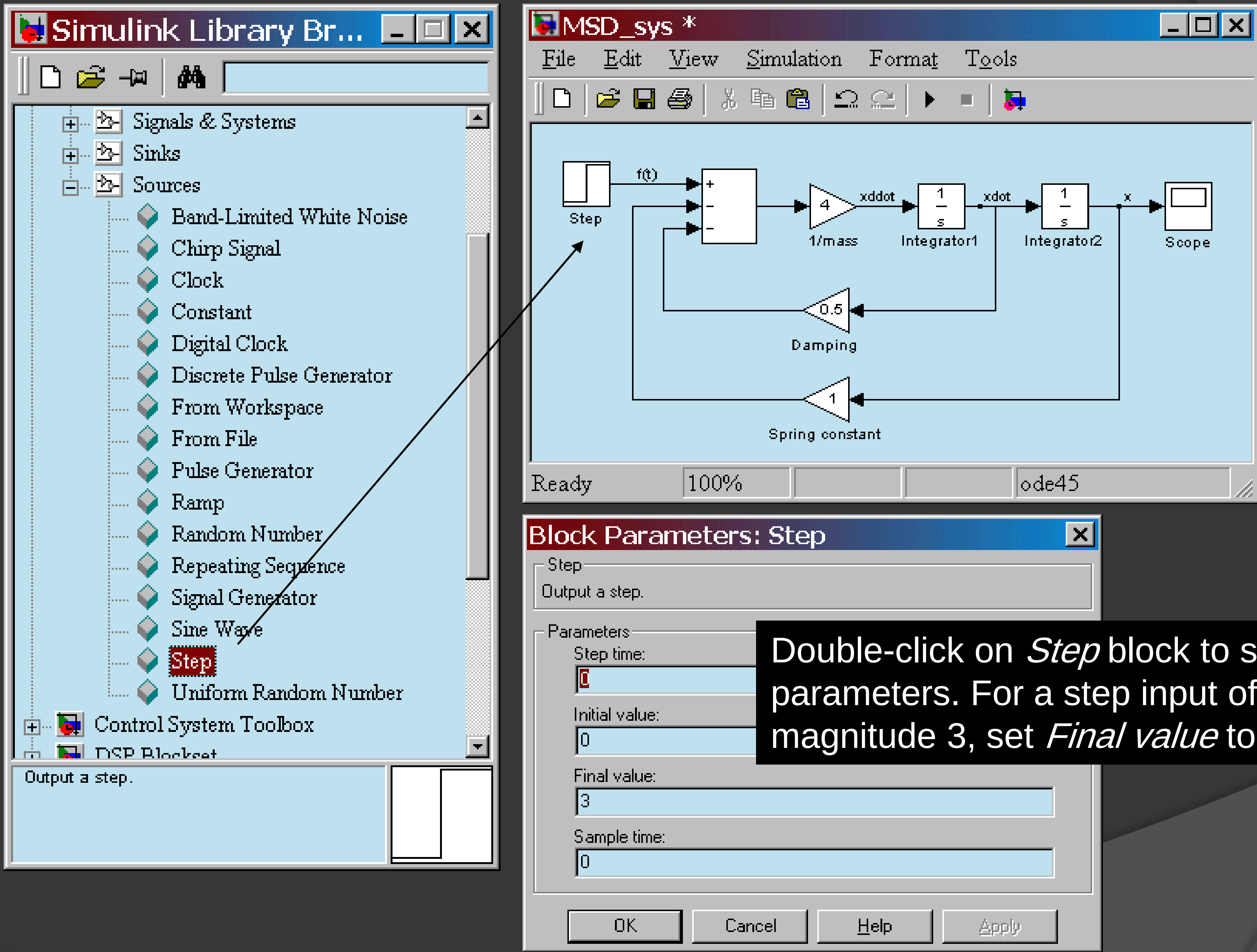




Complete the model

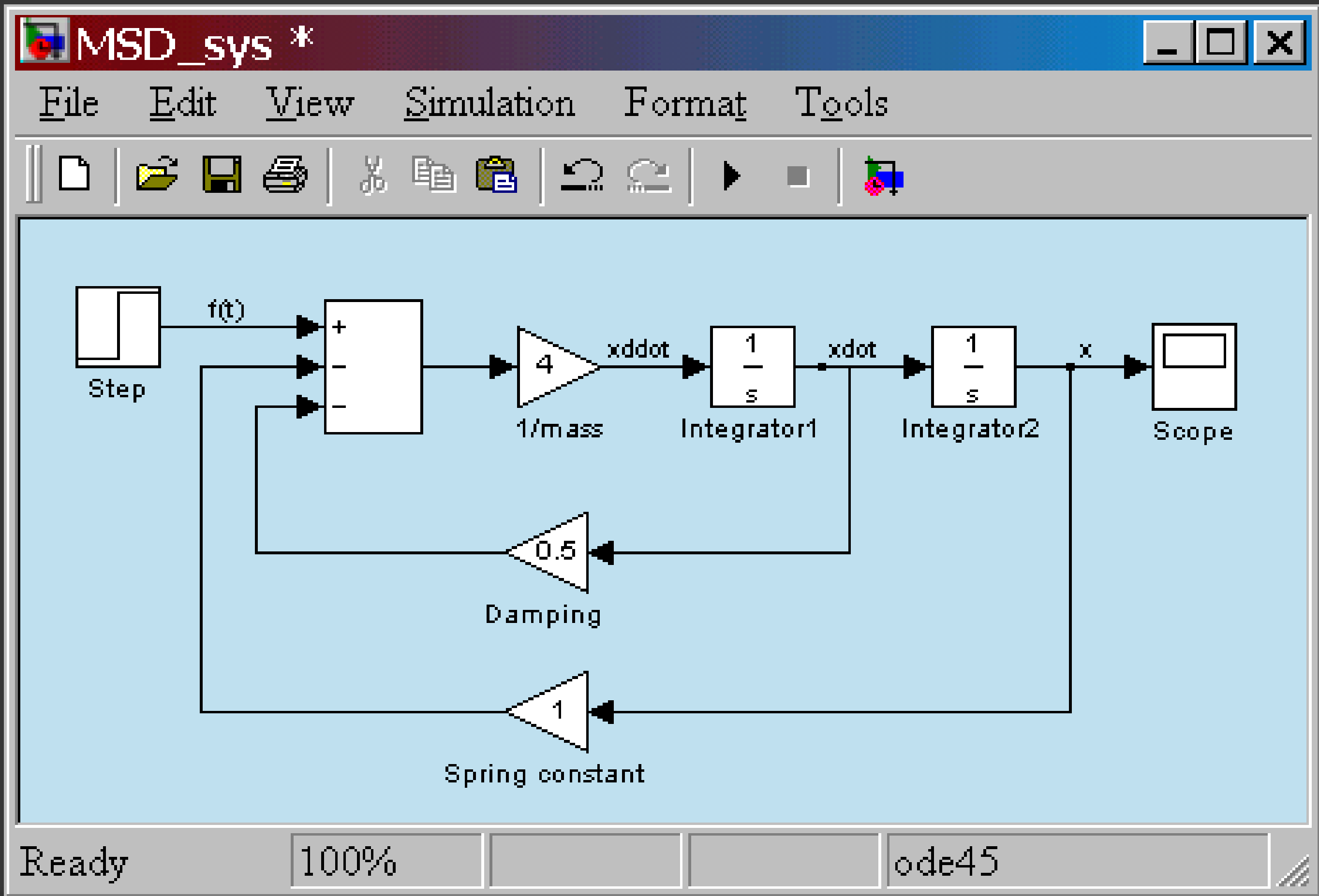
- Bring all the signals and inputs to the summing block.
- Check signs on the summer.



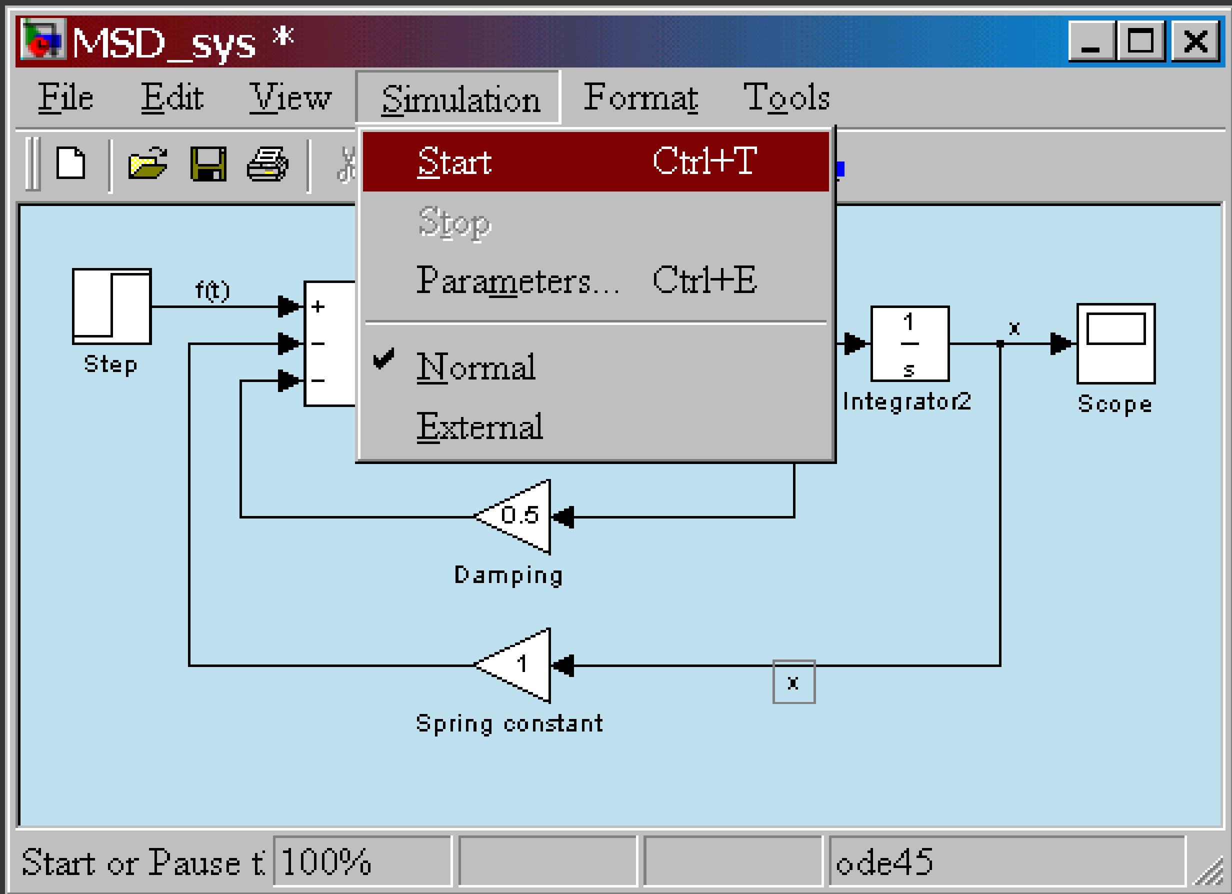


Double-click on *Step* block to set parameters. For a step input of magnitude 3, set *Final value* to 3

Final Simulink model



Run the simulation



Report

Construct a Simulink model to plot the solution of the following equations for 0 < *t < 3*

$$\dot{x}_1 = -6x_1 + 4x_2 + f_1(t)$$

$$\dot{x}_2 = 5x_1 - 7x_2 + f_2(t)$$

where *f1(t) is a step function of height 3 starting at t = 0 and f2(t) is a step* function of height 3 starting at *t =1.*

Experiment 8

Dc servo motor system
Matlab simulink

Philadelphia University

Electrical engineering Department

Control systems Laboratory

610416

Experiment Title:

Experiments number :

Date:

Student Name:

Student Number:

Supervisor Name: Eng.Esra'a Alghsoon

Build Simulink model on Matlab for Dc servo motor closed loop system

Experiment 9

Error in position control

Philadelphia University

Electrical engineering Department

Control systems Laboratory

610416

Experiment Title:

Experiments number :

Date:

Student Name:

Student Number:

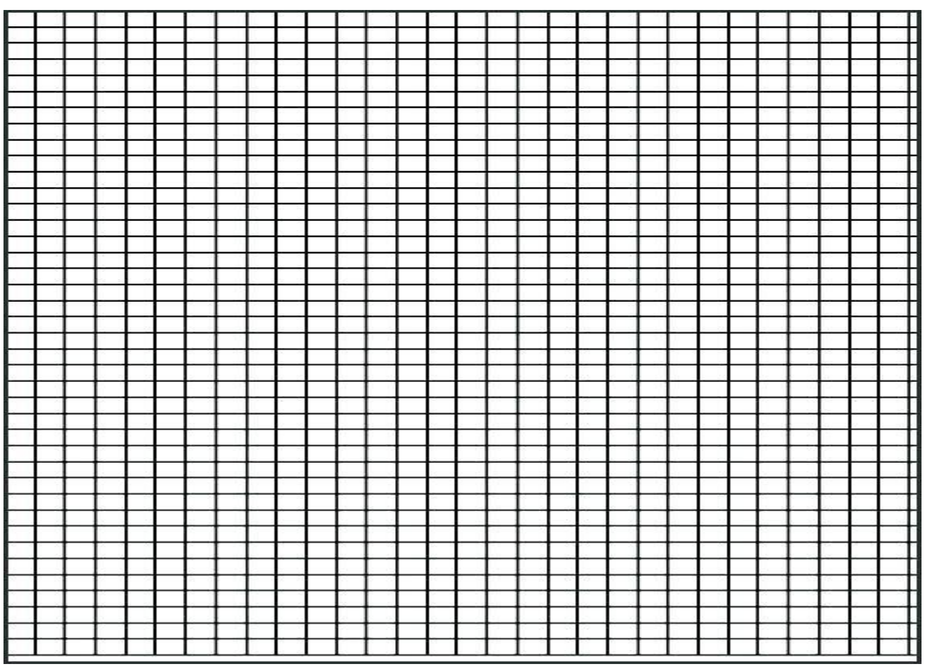
Supervisor Name: Eng.Esra'a Alghsoon

Introduction

Connect the modules that you need it in this experiment and follow the procedure steps on your manual to complete table below:

U157 Position	U158 Position	Error signal
180°	180°	
200°	180°	
220°	180°	
240°	180°	
180°	200°	
180°	220°	
180°	240°	

- Construct graphs Showing Position angles versus error voltage



Notes :

1-

2-

Conclusion

Experiment 10

Closed Loop Position Control

EXPERIMENT 10. CLOSED LOOP POSITION CONTROL

A. BACKGROUND THEORY

A closed loop position control system, as shown in Fig. 10-1, is a feedback system with the feedback signal carrying information about the differential position between the input and the output. The feedback signal is feedback to the amplifier in such a way to reduce the position error to zero.

In Fig. 10-1, A1 is the error signal generator, A2 is the error amplifier and A3 is the motor driver.
The desired position information (input) is given to the system through Pi potentiometer. When the position between the Pi and the Po is different, the error signal generator develops output which is amplified and applied to the motor. The motor rotates in such a direction to reduce the error voltage to 0.

As was the case with the servo motor in the previsous experiments, the gain of the amplifier needs to be high.
Otherwise, there will be substantial detection error in the system which reduces the sensitivity of the loop. This is called deadband in the system.

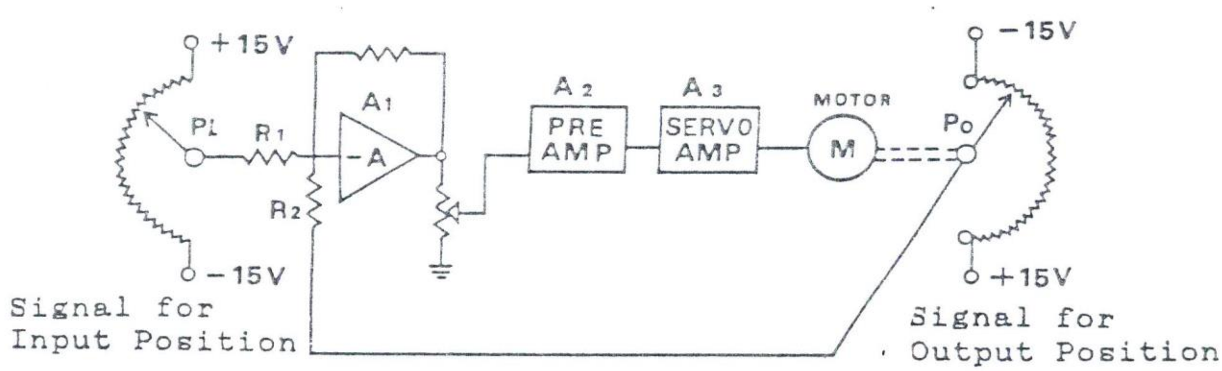


Fig. 10-1 Equivalent System Diagram of Experiment 10

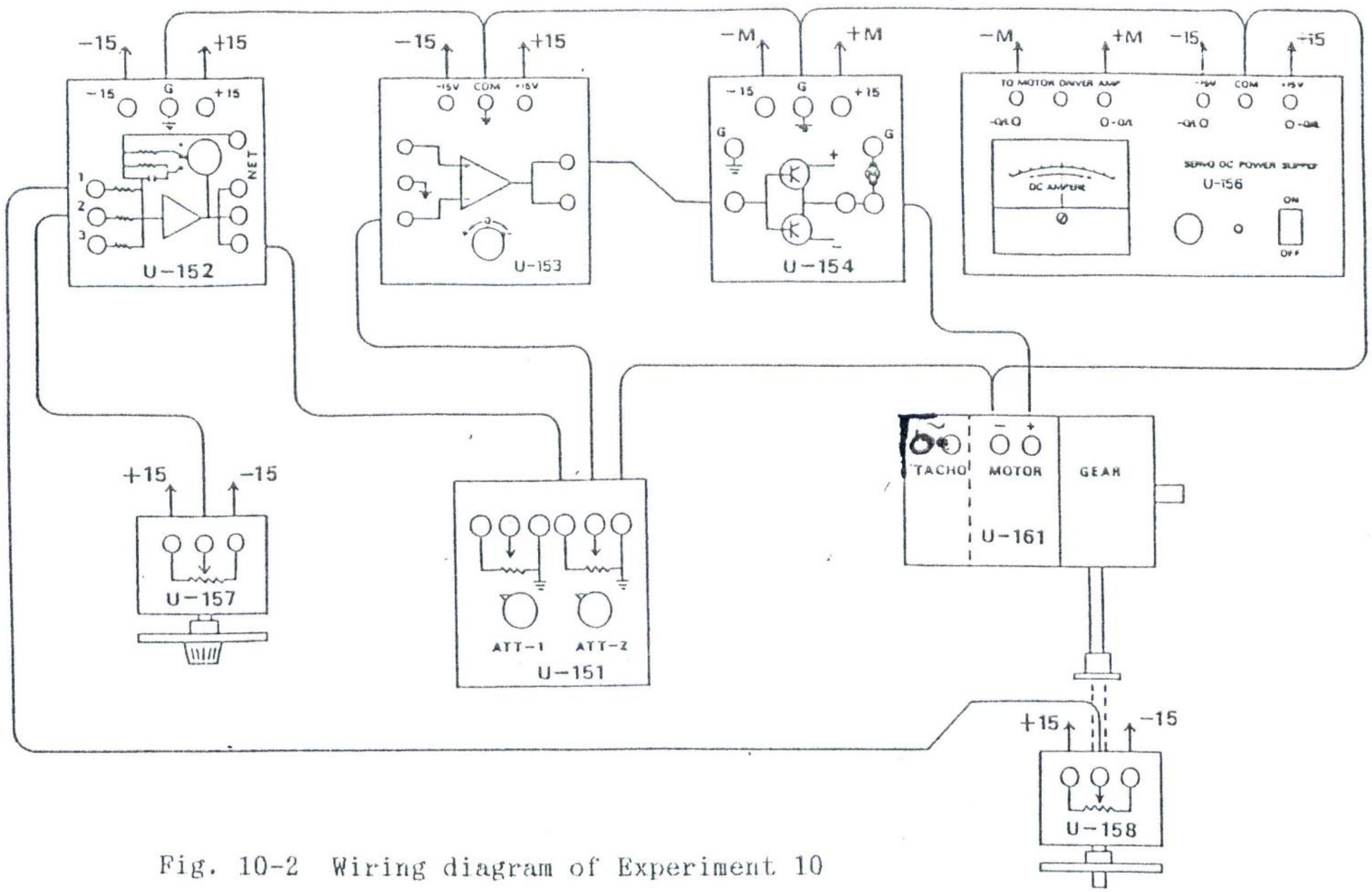


Fig. 10-2 Wiring diagram of Experiment 10

Philadelphia University

Electrical engineering Department

Control systems Laboratory

610416

Experiment Title:

Experiments number :

Date:

Student Name:

Student Number:

Supervisor Name: Eng.Esra'a Alghsoon

Introduction

Part1: Connect the modules that you need it in this experiment and follow the procedure steps on your manual to complete table below:

Clockwise				
Input Position	Output Position Attenuator =7	Output Position Attenuator =5	Output Position Attenuator =3	Output Position Attenuator =1
0°				
10°				
20°				
30°				
40°				
50°				
60°				
70°				
80°				
90°				
100°				
110°				
120°				
130°				
140°				
150°				

- Construct graphs Showing Position angles versus error voltage for different values of attenuator (Choose one angle)

Notes :

1-

2-

Part2:Automatic Position Control

• Carry out the circuit of fig. 4.5.5
• Set a null load value acting on the knob of the mechanical brake
• Set the PID CONTROLLER with the PROPORTIONAL knob turned to the maximum value and the INTEGRATIVE one to the minimum
• With the set-point apply a 0-Volt voltage and read the position, expressed in degrees, reached by the indicator set on the external unit TY36A/EV

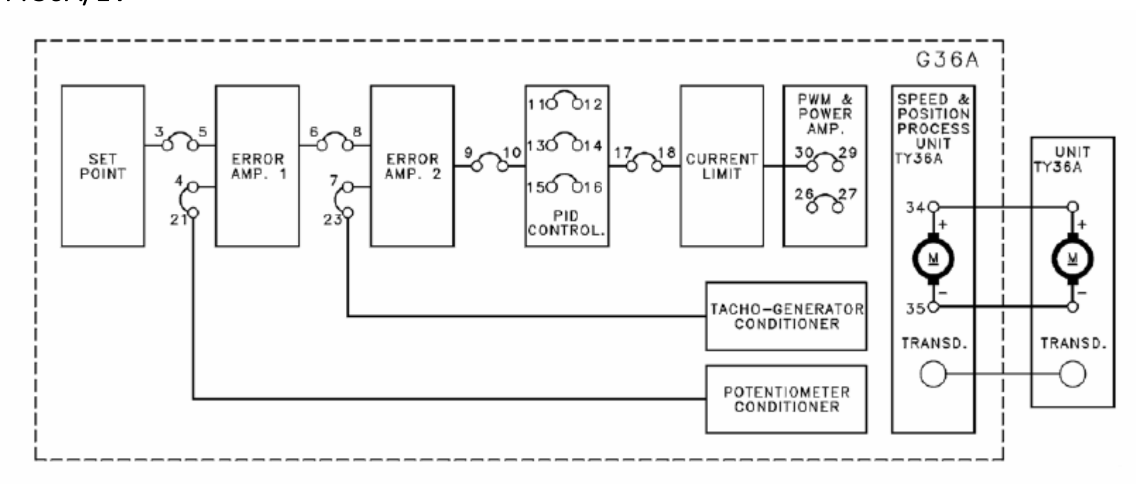


FIG. 4.5.5

SET POINT	ANGULAR POSITION
0	
1	
2	
3	
4	
5	
6	
7	
8	

TAB. 4.3

- Fill the table 4.3 with the measurement
- Repeat the same measurement f or all the voltage values of the table
- Take back the set-point voltage to 0V
- Apply a significant load (which does not block the motor) by acting on the brake knob
- Repeat the same measurements with null load
- Report the set-point voltage/angular position diagrams in the two cases of null load and load different from zero in a figure like the 4.5.2.
- Repeat the last measurements with negative set-point voltage values.

Conclusion