Experimental Instructions of Basic Control Theory For engineering students of SMU

Experiment allocation:

Experiment 1 – ALL

Experiment 2 – Groups 1, 4, 7, 10, 13, 16

Experiment 3 – Groups 2, 5, 8, 11, 14, 17

Experiment 4 – Groups 3, 6, 9, 12, 15, 18

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Experiment 1 Step response of a first-order system

Objective

1. This experiment help students learn the operation method of the experiment equipments.
2. It also help students become familiar with transfer function and characteristics of first-order systems.

Equipment

1. The experiment box especially for control theory.
2. Ultra-low-frequency dual-channel oscilloscope

Experiment content

1. Recognize and understand the analog circuit of the first-order system.
2. Measure the step response of the first-order system and observe how the variation of parameters affect the step response.

Theory

Connect the circuits to form a first-order system according to the block diagram and analog circuit diagram shown respectively in figure 1 and figure 2.

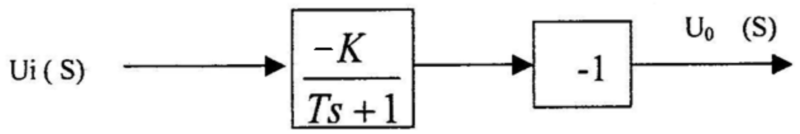

Figure 1

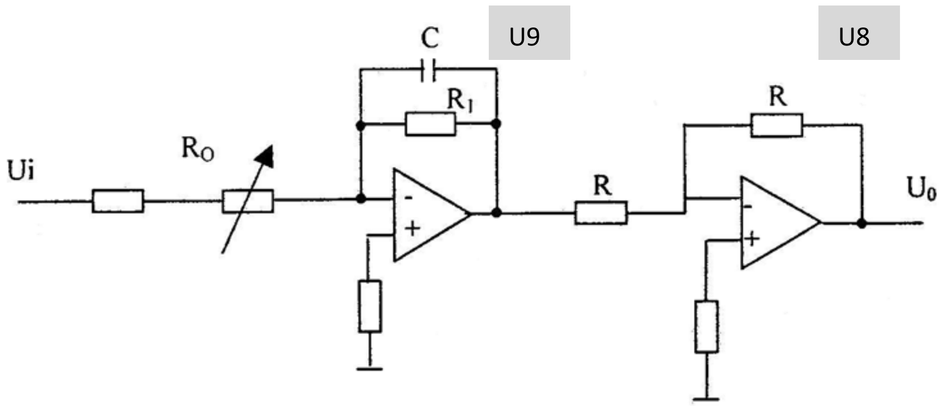

Figure 2

$$G(s) = \frac{U_0(s)}{U_i(s)} = \frac{K}{Ts+1} \qquad K = \frac{R_1}{R_0} \qquad T = R_1C$$

If a step signal is input to this circuit, the transient step response is an exponentially rising curve.

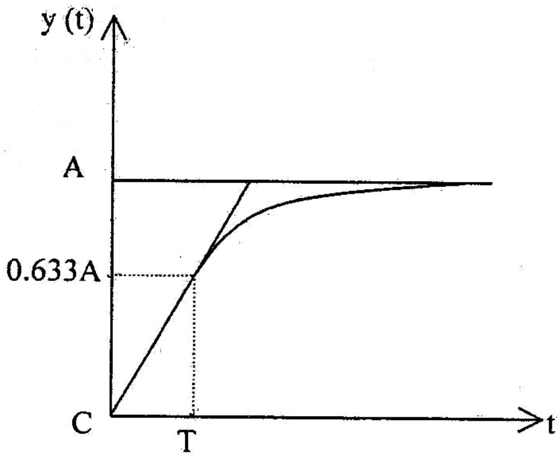

Figure 3

$$u_0(t) = A(1 - e^{-\frac{t}{T}})$$

$$u_0(t) = 0,\ when\ t = 0,$$

$$u_0(t) = 0.633A,\ when\ t = T$$

$$u_0(t) = A,\ when\ t = \infty$$

When it takes T time for $u_0(t)$ to rise to 0.633A, that is the definition of T.

In this experiment, the time constant T can be obtained by the values of $R_0,\ R_1,\ and\ C$.

Procedure

1. Students learn about and become familiar with the experiment box. A first-order system is formed by utilizing the analog circuit units U8 and U9. Pay attention to connecting “ground” of the op-amps to each other.
2. Take the periodical step signal as the input which is generated by unit U2. Connect the “ground(G)” of U2 to the “ground(G)” of the op-amp. Use the oscilloscope to observe the input and output signals of the system. Use the “frequency” button and the “amplitude” button to set the periodical step signal so that you can observe a whole step response process.
3. Tune the parameters to different values to observe the variation of the step response, and analyze the effect of parameters variation on the step response.
   a) For example, students can set $R_0 = 200K,\ R_1 = 200K,\ C = 2\mu F$, and then they get $T = 0.4s$.
   b) If they set $R_0 = 200K,\ R_1 = 200K,\ C = 1\mu F$, and then they get $T = 0.2s$.

Make sure to give these parameters a try.

Exercises experiment 1

1. Draw the circuit diagram.

2. Compare the measured value of T with the theoretical value, and analyze the reason why they do not coincide.

3. Record and explain the variation of the step response with respect to the variation of C.

Experiment 2 Step response of a second order system

Objective

In this experiment, students observe and analyze how the open-loop gain variation effects on the transient process of a second order system. Students should learn to measure the overshoot M_p and settling time t_s with respect to the gain K.

Equipment

1. The experiment box especially for control theory.
2. Ultra-low-frequency dual-channel oscilloscope

Experiment content

1. Observe the step response curve of the second-order system with respect to different values of open-loop gain.
2. Learn the method of measuring the overshoot M_p and settling time t_s by the oscilloscope.

Theory

Connect the op-amps circuits to form a second-order system according to the block diagram and analog circuit diagram shown in figure 1,2 and 3.

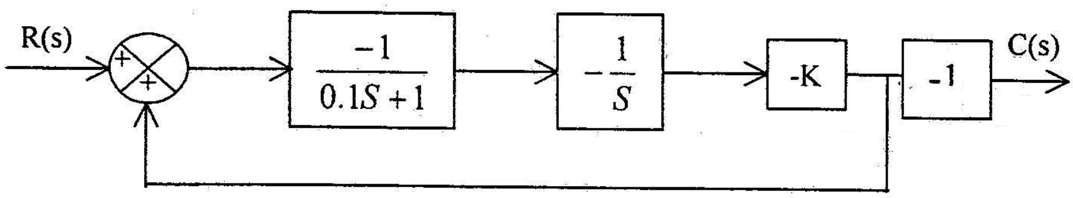

Figure 1

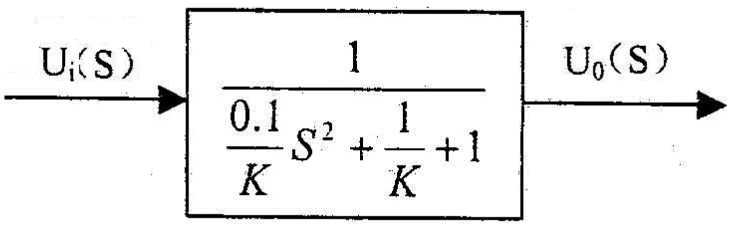

Figure 2

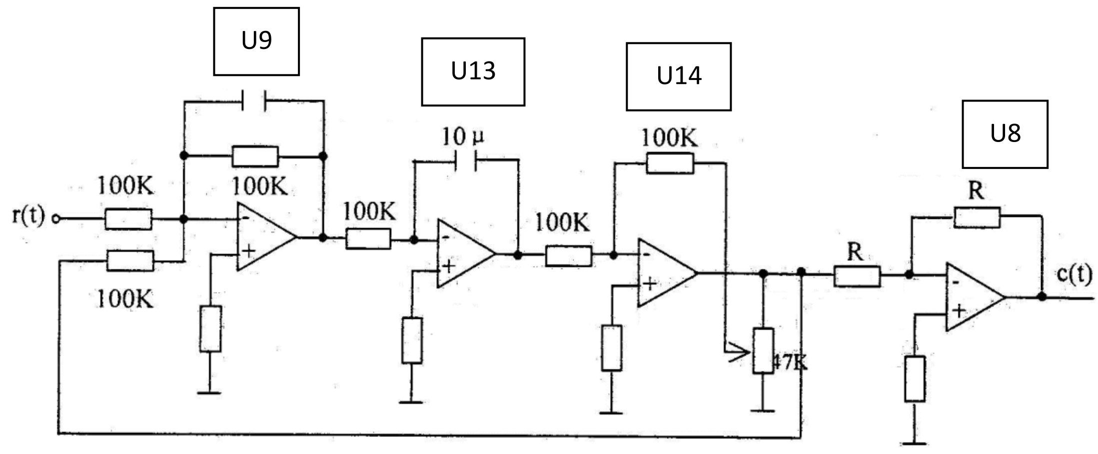

Figure 3

The transfer function is,

$$G(s)=\frac{C(s)}{R(s)}=\frac{1}{T^2s^2+2\xi Ts+1}=\frac{\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2}$$

$$\xi=\frac{1}{2}\sqrt{\frac{1}{0.1K}} \qquad \omega_n=\frac{1}{T}\sqrt{\frac{K}{0.1}} \qquad K=\frac{1}{\beta} \qquad \beta=0\sim 1$$

When $K>\frac{1}{0.4}=2.5$, $0<\xi<1$

When $K\rightarrow\infty$, $\xi=0$

When $K\leq\frac{1}{0.4}=2.5$, $\xi\geq 1$

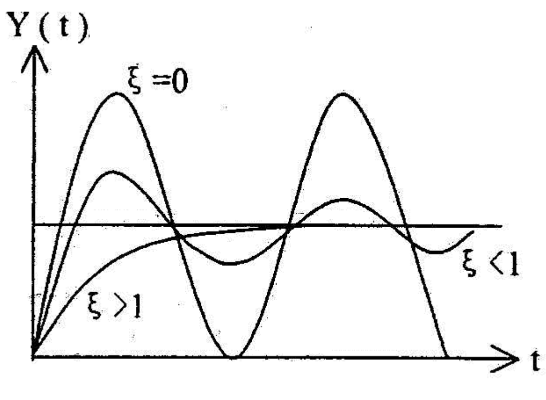

Figure 4

Procedure

1. Connect the units U9, U13, U14 and U8 to form the system. Only after the teacher has checked the circuit and confirmed, the circuit could be powered on.
2. Power on the oscilloscope and tune the scanning rate appropriately.
3. Vary the gain K to get variant ξ. Observe the variation of the curves of transient process and measure M_p and t_s.

Exercises experiment 2

1. Draw the circuit diagram.

2. Draw step response curves of the transient process with respect to different values of ξ ($0<\xi<1$, $\xi=1$, $\xi>1$).

3. Write down your measurement of M_p and t_s .

Experiment 3 Measurement of static error

Objective

In this experiment, students learn to measure the static error of a feedback system. Students also observe how the type of system, the open-loop gain and the input signal effect on the static error.

Equipment

1. The experiment box especially for control theory.
2. Ultra-low-frequency dual-channel oscilloscope

Experiment content

1. Observe how the type of system, the open-loop gain and the input signal effect on the static error.
2. Learn the experimental method of observing and analyzing the static error of a system.

Theory

Connect the op-amps circuits to form a type 0 feedback system according to the block diagram and analog circuit diagram shown in figure 1, and 2.

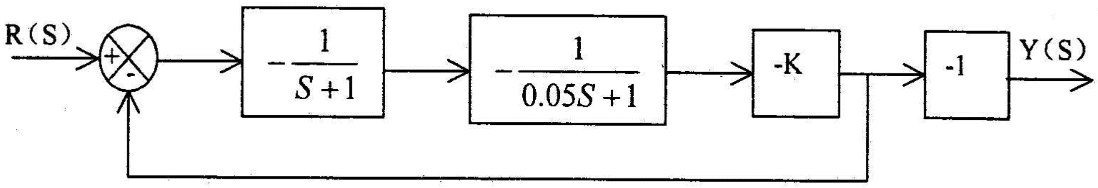

Figure 1

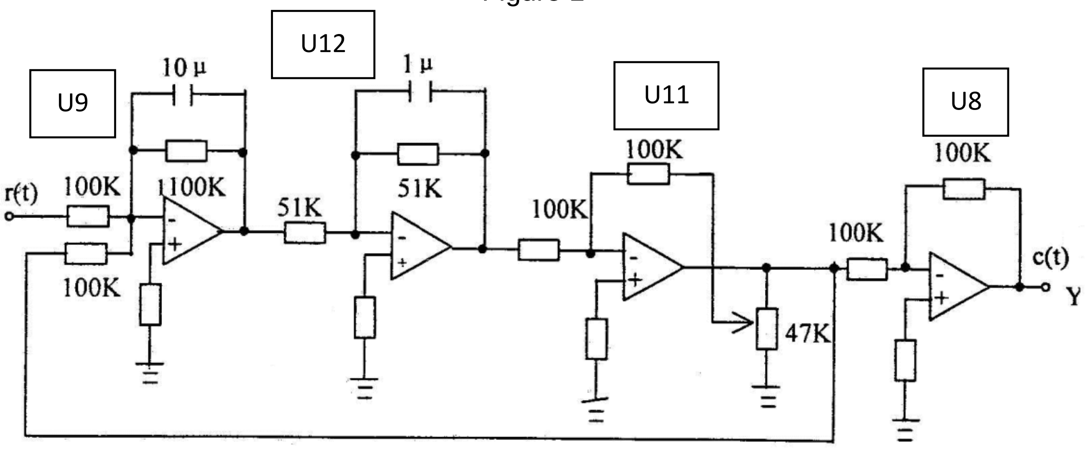

Figure 2

Requirement for preparation of this experiment

1. The calculation method of static error. The relationship between static error and the open-loop gain, the number of integral factors, and the input signal.
2. The open-loop transfer function of the above-mentioned type 0 system is $G(s) = \dfrac{K}{(s+1)(0.05s+1)}$.

Procedure

1. Connect the units U9, U12, U11 and U8 to form the system according to figure 2.
2. Power on the oscilloscope and tune the scanning rate appropriately.
3. When the system is input a step signal, tune the “47K” potentiometer so that the open-loop gain K varies. Observe the effect of variation of K on the static error e_p ($e_p = \dfrac{r_0}{1+K}$).
4. When the system is input a ramp signal, observe the static error e_v. Tune the “47K” potentiometer so that the open-loop gain K varies. Think of the effect of K on e_v and give the reason for this.

Exercises experiment 3

1. Draw the circuit diagram.

2. Compare the experimental result with theoretically calculated result. Analyze and explain the difference if there is difference.

Experiment 4 Experiment of the stability of a feedback system

Objective

In this experiment, students learn to observe and analyze how the system's structure and parameters effect on stability of the system.

Equipment

1. The experiment box especially for control theory.
2. Ultra-low-frequency dual-channel oscilloscope

Experiment content

1. Observe the stability of the system by the step response curve.
2. Learn the experimental method of observing and analyzing how the open-loop gain *K* effect the stability of a system.

Theory

Connect the op-amps circuits to form a feedback system according to the block diagram and analog circuit diagram shown in figure 1, and 2.

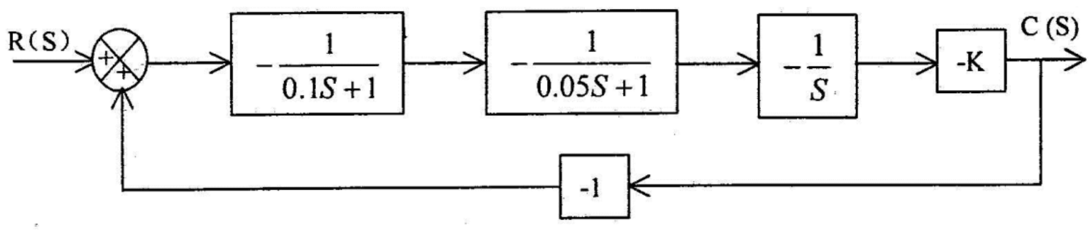

Figure 1

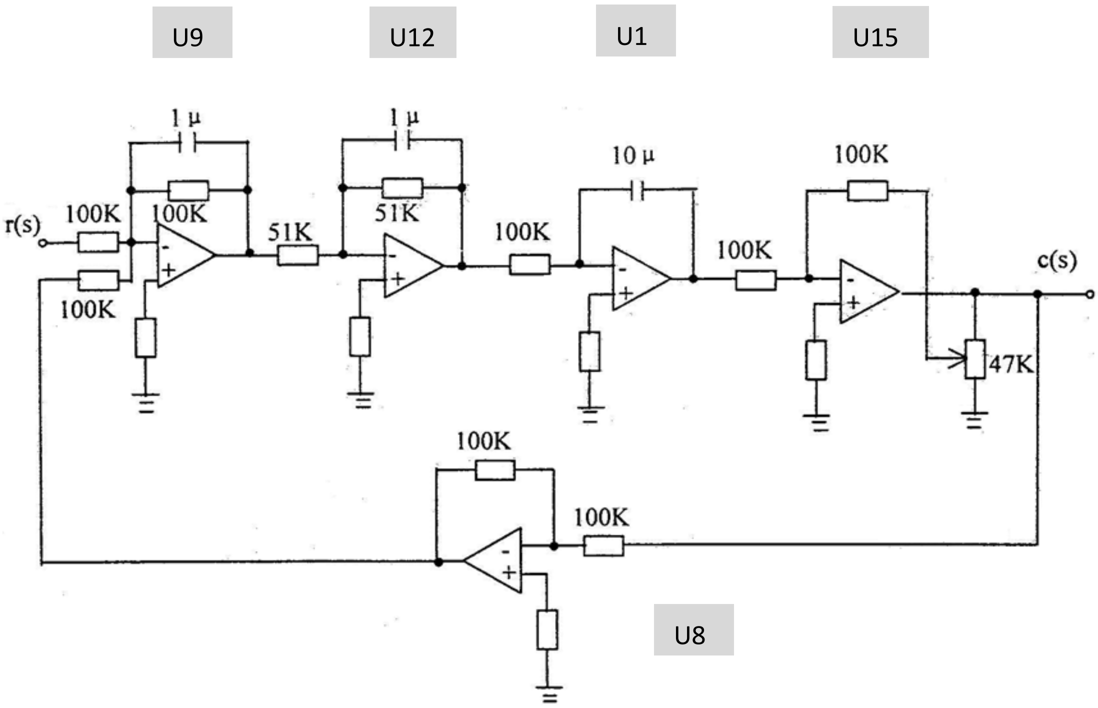

Figure 2

Procedure

1. Connect the units U9, U12, U11, U15 and U8 to form the system according to figure 2.
2. Power on the oscilloscope and tune the scanning rate appropriately.
3. Observe the stability variation of the system when the open-loop gain *K* varies.
4. Record the number of oscillation of the transient process with respect to variant open-loop gain *K*.
5. Observe the stability of the system when the unit U12 is configured as an integrator (the 51K resistor is opened).

Exercises experiment 4

1. Draw the circuit diagram.

2. Compare the experimental result with theoretically calculated result. Analyze and explain the result.