Feedback

Computer Assisted Learning

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Modular Servo System - Sample and Hold Unit SH150M

MS150-5

Technology Training for tomorrow's world

Modular Servo System MS150
Book 5

Sample and Hold
Unit SH150M

Feedback

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Sample and Hold

Unit SH150M

CONTENTS

INTRODUCTION

SECTION 1

The development of control systems, communication networks, etc has evolved a new method of transmitting information. This new method is known as the sampled data system and deals with the way that information within a system can be sent at discrete intervals of time and still operate the system successfully.

In the following assignments a series of practicals will develop sampling ideas step-by-step to show how they can be applied to such systems as servomechanisms and process controllers.

The basic ideas are simple and will enlarge the understanding of a student studying control systems.

To simplify the idea of sampling, let us consider the following situation. A radar operator on board a ship will receive information about the position of another ship A every time the beam of the rotating antenna traverses A as in fig 1(a).

The operator receives his information using a slow sweep oscilloscope. The electron beam is continuously sweeping from the centre of the CRT to the edge, rotating a fraction on each sweep. If a return signal is received at any instant, then it is shown as a bright blip on the screen. The blip on the screen of fig 1(b) would shown A on a heading of 45° at a distance of 8 miles. The probiem here is that the information is only received at discrete intervals of time but the afterglow of the phosphor forming the CRT screen makes it possible for the information to be continued to be shown. On the next sweep the position blip may be renewed or moved.

For such a system to operate properly

a) The ship A must not move very far between sweeps, and

b) The afterglow must persist just long enough to show the position of A between sweeps,

otherwise there would be confusion with two or more blips showing on the screen.

If we consider a voltage analogy, the 150M Sample/Hold unit is able to sample the instantaneous values of a signal voltage at predetermined rates and hold this value as an output till the next sample instant.

It is the idea that there must be a proper relationship between the sweep speed of the trace and possible movement of A that allows us to develop a theorem known as the Sampling Theorem. For the complete recovery of a given signal, sampling must take place at least twice as fast as the highest frequency component. A more rigorous treatment of this theorem is given in Appendix 2.

The meaning of this theorem is brought out more clearly if we consider the following example. A disc with a slot at position A can be rotated as in fig 2. Behind the disc a pendulum swings from position A'. An observer stationed at X will just catch a glimpse of the pendulum as it rotates past A and will see it again when the disc rotates 180° to B. On the face of it he will seem to have no way of knowing how fast the pendulum is swinging as he will only see the extremities and will have no other information about the intermediate positions of the pendulum.

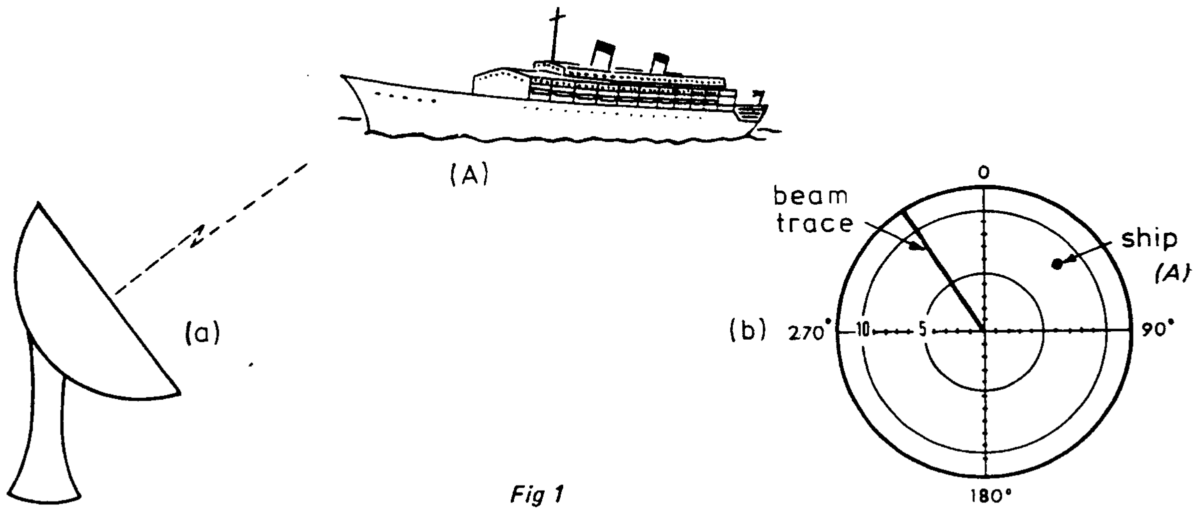


Fig 1

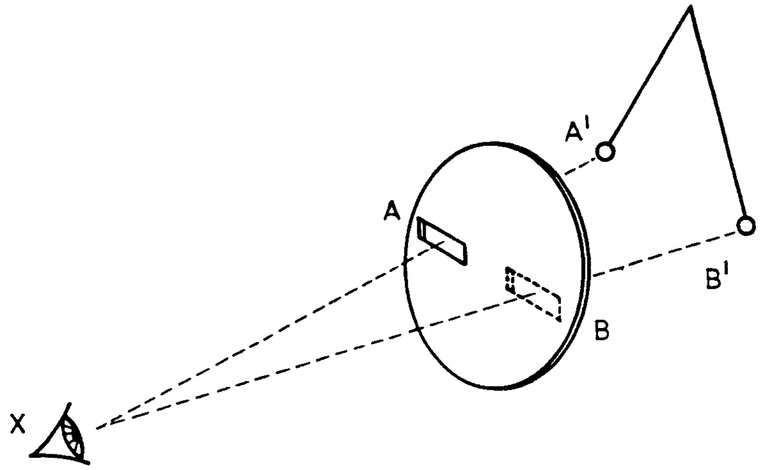


Fig 2

In actual fact if the disc is rotated out of step, let us say slightly faster, then on each rotation a different intermediate step will be viewed. The amplitude swing of a pendulum about a fixed point can be plotted as a sinusoidal waveform. This can be taken as the input curve of fig 3 while the distance of the bob from the disc centre is shown as discrete outputs on the sample graph.

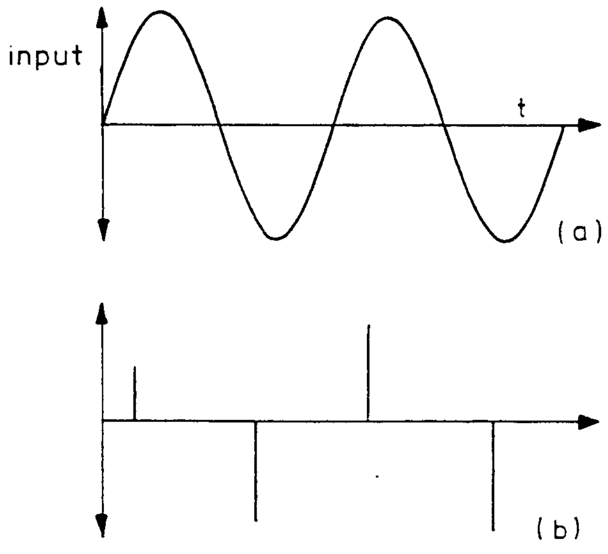


Fig 3

Again, considering a voltage analogy, the position of the pendulum may be represented by a sinusoidally varying voltage. The samples are then narrow pulses, whose amplitude corresponds to the waveform amplitude at the sampling instant. Provided samples are taken at least twice per cycle (of the highest frequency component present) then the information content of the waveform is retained. Under such circumstances, the input may be recovered completely,

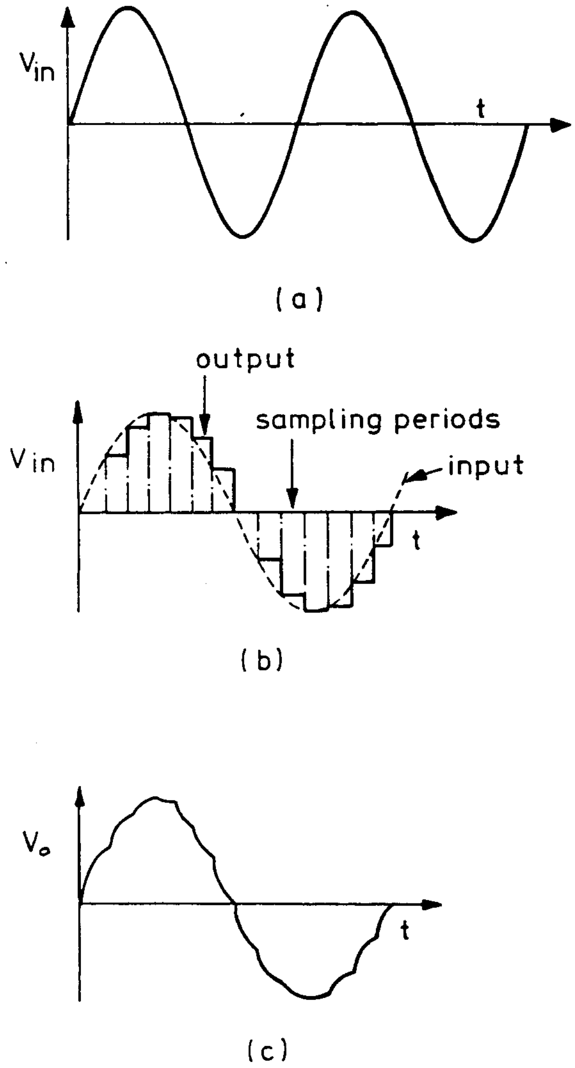


Fig 4

provided a filter of suitable characteristics is employed. If too low a sampling frequency is used, then the information is not retained and false outputs can appear.

In the SH150M, the input voltage is held at its instantaneous value for the duration of each sample period as shown in fig 4(b).
Simple filtering is provided to examine the effect of low pass filling the output. This gives a closer approximation to the input signal, see fig 4(c).

These features are examined in a practical in Assignment 2.

Sample and Hold circuits are classified according to their transfer function. A circuit called a Zero Order Hold, fig 5, is used in the SH150M. Its output is a pulse whose height corresponds to the sample value and width to the sample period.

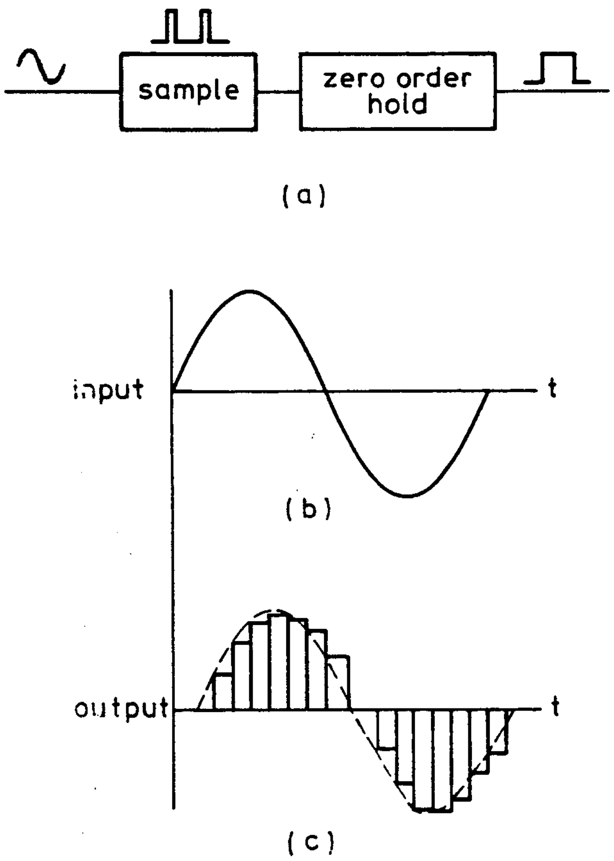


Fig 5

Using these introductory remarks the following assignments will take you step-by-step through a series of practicals showing, initially, how the controls on the 150M are used and their effect on varying waveforms

With this basic information the assignments then show the purpose of the sampling oscilloscope and the basic characteristics of a sample control system using the 150 Modular Servo. The system is then extended to use also the PT326 Process Trainer and PCS327 Process Control Simulator.

Object

To introduce the basic sampling techniques and show how the controls on the module can be used.

Equipment required

Quantity	Apparatus
1	SH150M Sample/Hold Unit
1	PS150E Power Supply Unit
1	FG600 Functional Generator or similar generator
1	Dual-trace Oscilloscope

Approximate time required

One and a half hours

Prerequisites

Nil

PRELIMINARY PROCEDURE

1. Interconnect the units as shown in fig 1.2.

2. On the SH150M Sample/Hold set the switches:

SAMPLE/FOLLOW	to Follow
TRIGGER/FREE	to Free
EXT/INT	to INT
+ve/-ve	to +ve
Frequency multiplier	to X10
Sampling frequency knob	to 10

3. On the FG600 Function Generator set:

   Frequency range at 10-100Hz
   Frequency dial to 1, i.e 10Hz
   Function Switch for triangular waveform output
   Output amplitude to 10V p-p.

4. On the dual-trace oscilloscope set:

   Timebase 10ms/cm
   Amplifiers 2V/cm

5. Connect the PS150E Power Supply, FG600 Function Generator and Oscilloscope mains plug into the mains sockets. DO NOT switch on yet.

DISCUSSION AND EXPERIMENTAL PROCEDURE

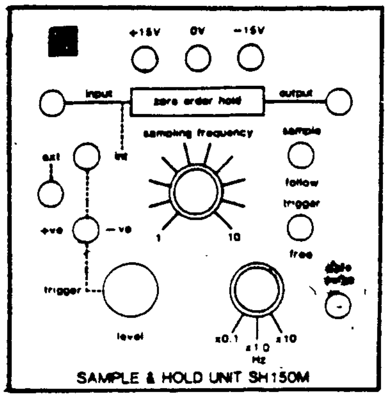


Fig 1.1

In fig 1.1 is a mimic of the SH150M Sample/ Hold Unit. Let us examine the controls and terminals forming its deck.

Power Supplies

As the unit is designed to operate using the Power Supply PS150E unit from the Modular Servo kit, the power supplies have been designed for ±15V. The sockets together with the 0V input are located at the top of the deck. The regulated ±15V outputs from the 150E Power Supply unit are intended to be used as the voltage source.

Practical 1.1 Follow Control

We will first examine on an oscilloscope the follow function of the ZERO ORDER HOLD.

Ensure that you have followed the instructions in the Preliminary Procedure and then switch on.

Q1.1 What is the reason for using the trigger output on the oscilloscope?

Adjust the trigger controls on the oscilloscope for a steady display.

Q1.2 On the oscilloscope screen does the output waveform follow the input waveform?

Now set the function switch on the FG600 to sinusoidal waveform and then to a square waveform.

Exercise 1.1

With all three waveforms, did the output waveform follow the input waveform on the oscilloscope?

What was the gain in each case?

Sampling

There are three controls to regulate the sampling facility on the SH150M. The SAMPLE/FOLLOW switch when set to sample will switch in the sampling circuits.

The sampling period is controlled by the SAMPLING FREQUENCY control with divisions 1 to 10 over frequency ranges of X10 giving up to 100Hz, X1 giving up to 10Hz, and X0.1 giving up to 1Hz.

At the moment the settings are a range of X10 and the frequency set to position 10.

Q1.3 What will be the sampling period?

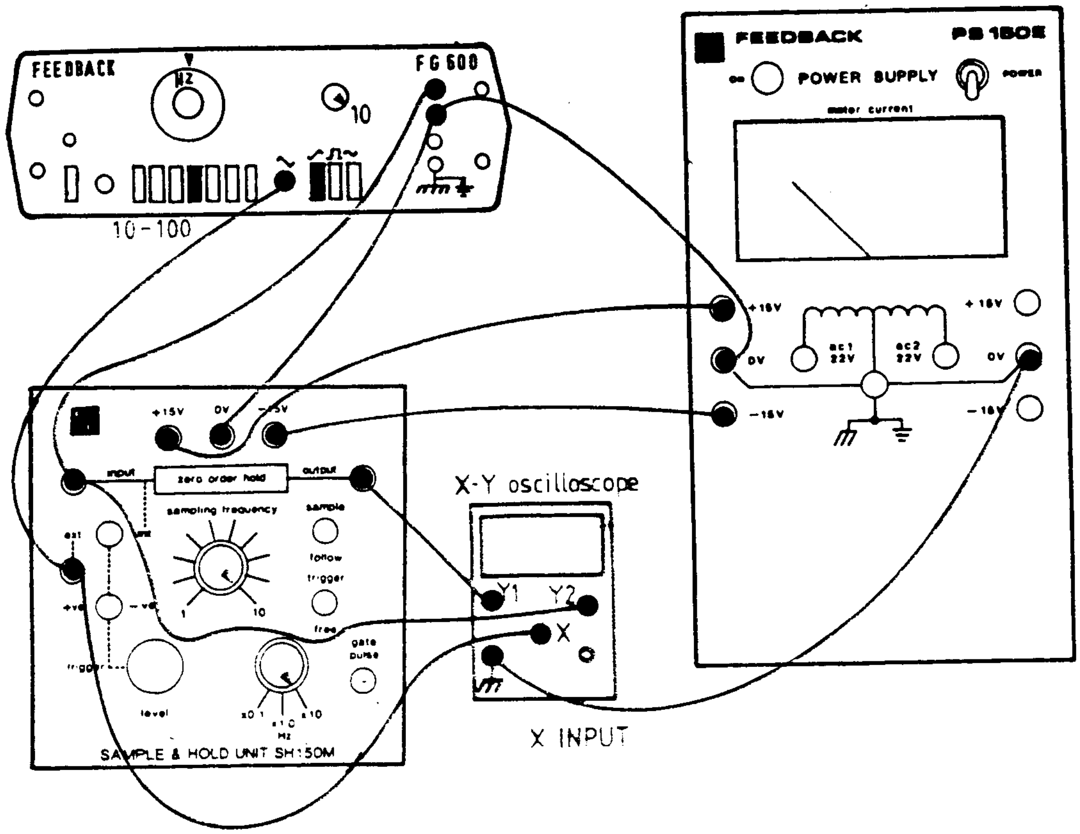


Fig 1.2

Practical 1.2 Sample Control

To see how the 150M samples, keep the FG600 function generator on the triangular waveform output and switch to SAMPLE: you should then obtain waveforms as in fig 1.3. Make a tracing of the input and output waveforms on the oscilloscope screen.

Switch the FG600 to first sinusoidal and then, square waveform outputs, each time observe the tracings of the waveforms on the oscilloscope screen.

Switch the FG600 back to a triangular waveform output and set the sampling frequency control to position 5. Make tracings once more of the outputs on the oscilloscope screen.

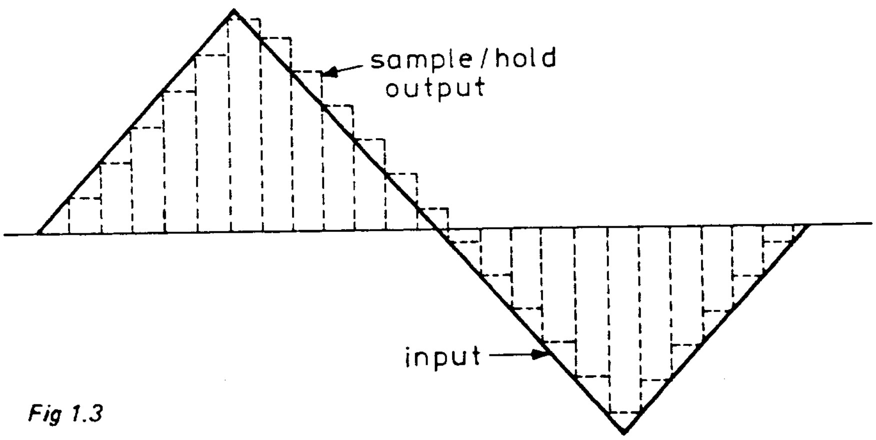


Fig 1.3

Exercise 1.2

Draw horizontal axes on the four sets of waveforms and mark the quarter-cycle intervals.

a) What effect has the sampling frequency on the reproduction?

b) Is there any effective difference in the sampling of the three types of waveforms?

Q1.4 What advantage would there be in having triggering facilities in a sample/hold unit?

Triggering Controls

There are four trigger controls and an output terminal. When the TRIGGER/FREE switch is set to Trigger, the triggering circuits can be used.

With the LEVEL control the value of voltage at which triggering will occur can be set and the +ve/-ve switch determines whether it is on the positive or negative-going slope of the input waveform.

The EXT/INT switch allows the SH150M to be triggered from an external source or from its own internal triggering circuit. When external triggering is used, the EXT terminal is connected to the external triggering source.

Practical 1.3

To observe the effect of triggering, set the TRIGGER/FREE switch to Trigger.

Q1.5 What will the effect of varying the level control be?

Now vary the level control and you should be able to observe the effect as in fig 1.4.

You may need to vary the sampling frequency to make the effect clearer.

Q1.6 Why should varying the sampling frequency control affect the triggering point in a sample period?

Then set the +ve/-ve switch to negative and vary the triggering level, so that by setting the polarity switch you now trigger on either slope of the input waveform.

It is possible to inspect the pulse that triggers each sample period by taking an output from the terminal GATE PULSE. Transfer the oscilloscope lead from the input of the SAMPLE/HOLD to the Pulse Gate terminal so that you will see the following waveform as in fig 1.5.

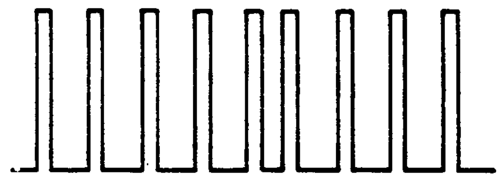


Fig 1.5

Vary again the level control and examine both waveform slopes.

Now vary the sampling frequency as well as the level control and note the effect on the triggering pulse.

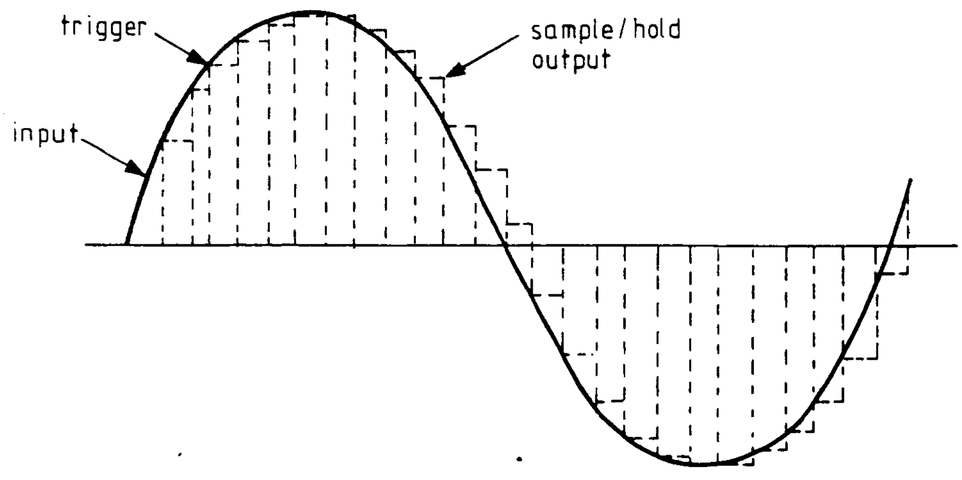


Fig 1.4

Exercise 1.3

Set the controls so that triggering is at +135° as in fig 1.6 and the sampling frequency control to position 6.5.

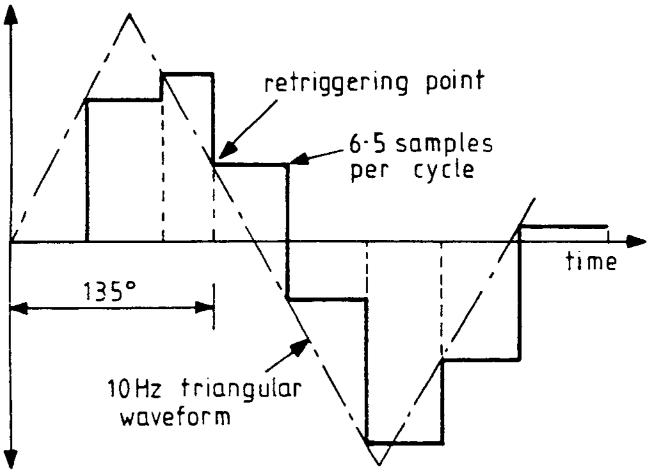


Fig 1.6

Take a tracing of the waveforms on the oscilloscope.

Calculate the sampling period and the point at which triggering will occur and compare it with your traced result.

Now set the FG600 function generator to give a triangular 1 Hz waveform output.

Set the frequency range switch on the 150M to X1.

Reduce the time base speed on the oscilloscope to 20ms/cm.

The output will still be synchronised but at a lower speed.

Q1.7 Do you think that using this technique, sampling can be carried out at any frequency?

Practical 1.4

Lastly to use the external triggering facility of the SH150M, set the EXT/INT switch to External and the +ve/-ve switch to the slope you wish to investigate. The external triggering terminal is already connected to the triangular wave output of the FG600. Set the range switch to X1. Connect the input and gate pulse to the oscilloscope Y-inputs.

Return the oscilloscope settings to that in the Preliminary Procedure. On the FG600 function generator set the frequency to 10Hz with a triangular waveform output.

You will now be able, using the level control, to vary the position of the external triggering pulse on the slope of the input waveform. Check that it is the triggering pulse by noting whether it is affected when the sampling frequency control is varied. As a further check remove the EXT lead, set the EXT/INT switch to Internal and again vary the sampling frequency control.

Exercise 1.4

Finally, carefully read Appendix 2 on the Sampling Theorem and then suggest a type of filter and its mode of operation, that would reduce the guard space between the spectra at the expense of increased but tolerable delay.

APPLICATIONS

The uses to which sampled data can now be put are numerous.

A frequent use for the technique is in sampling data. Very often a large number of different signals must be sent over one communications link. We can take a military application where a guided missile has to transmit back certain basic information so that alterations in its course may be made. This information would include details of its velocity, acceleration, altitude, temperature, course, rate of fuel burn, etc. Each variable can be given its own channel or time share. One simple method of using time sharing is for each variable to be sampled; the sampling rate and duration of each sample can then be determined by the number of pieces of information being used and the fact that the missile will transmit for part of the time and the master station for the rest of the time. In such a case the received information can then be held as long as possible in the binary store of a computer.

The development of the computer has been a major factor in spreading the use of data sampling. In many applications it is essential to transmit positional information; the usual device to do this is the synchro. If the synchro data is digitised to maintain compatibility with the system, it can be transmitted by line or radio link and then fed into the reproducing unit, or servo, so that the required shaft position can be set.

If the line or radio link has to serve a number of stations, then the digitised data can be sampled. The output of the synchro will normally be in analogue form and so will need conversion to digital. At the other end there will again be a conversion to analogue to operate the servo. Such systems offer improvement in performance at expense of bandwidth.

The early development of automatic control in chemical and petroleum plant also has led to the extensive use of data sampling, whether in analogue or digital form. By this means settings of the multitude of process control valves that can be situated over a very wide area and sometimes in hazardous or concealed positions, can be centrally controlled, monitored and logged either by operators, automatic controllers or computers. Only by the use of data sampling can the multitude of signals be effectively transmitted and received.

A further widespread use of data sampling is in the numerical control of machines. Many machines are now controlled by a program fed into an external computer. Several machines may be time shared whilst if all the information for the various settings is to be transmitted in a minimum number of lines, then data sampling is the normal way by which this data is sent.

The set of assignments comprising this manual is designed to show you how the ideas that we have developed in this assignment can be used in applications such as the use of an oscilloscope with a low frequency band, with which to measure signals outside its range, and its use with servo and process control systems.

Object

a) To examine the effect of sampling various waveforms using a simple RC filter.

b) To demonstrate the sampling oscilloscope.

Equipment required

Quantity	Apparatus
1	Power Supply Unit 150E
1	Sample/Hold Unit 150M
1	Function Generator FG600
1	Oscilloscope with: Dual trace External triggering Frequency sweep Pulse brightness control input

Approximate time required

One and a half hours.

Prerequisites

Assignment 1.

PRELIMINARY PROCEDURE

1. Set the switches of the Sample/Hold 150M Unit to

SAMPLE/FOLLOW	to	Sample
TRIGGER/FREE	to	Free running
+ve/-ve	to	+ve
EXT/INT	to	INT

The frequency range selector to X10 and the sampling frequency adjuster to position 10.

2. On the function generator FG600 set the frequency range to 1 to 10Hz, the frequency line control to 10 and the waveform selector switch to sinusoidal.

3. On the oscilloscope set the:-

   Timebase to 50ms/cm
   Beams to 10V/cm

4. Interconnect the units as in fig 2.4.

5. Connect the mains plug on the FG600, 150M and oscilloscope to the mains sockets. DO NOT switch on yet.

DISCUSSION AND EXPERIMENTAL PROCEDURE

In Assignment 1 we showed how the 150M controls could be used.

Q2.1 What is the purpose of sampling a signal?

Q2.2 Why do we need to hold the signal value during the sampling period?

Q2.3 What advantage is there in triggering the sampling period at set signal values?

As a first practical in the assignment we are going to place a capacitor in the output circuit of the 150M to form a simple lag filter. In fig 2.1 we can represent the output impedance of the system sampled by a 1kΩ resistance and the value of the capacitance we shall be using will be 33μF.

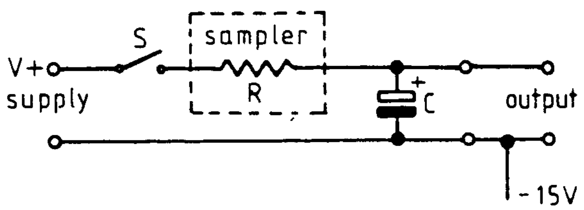


Fig 2.1

If we switch on the supply the output voltage across C will take time to virtually reach the supply voltage V. At any instant its value will be:

$v = V(1 - e^{-t/RC})$ volts   Eq. 2.1

and if we plot a graph of voltage v against time in seconds the resulting curve will be as in fig 2.2.

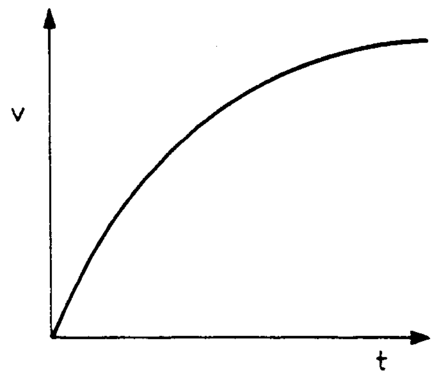


Fig 2.2

Again if we switch off the input, the way in which the voltage v across C decays will be of the form:

$v = Ve^{-t/RC}$ volts   Eq. 2.2

and the graph of the voltage v against time in seconds will be as in fig 2.3.

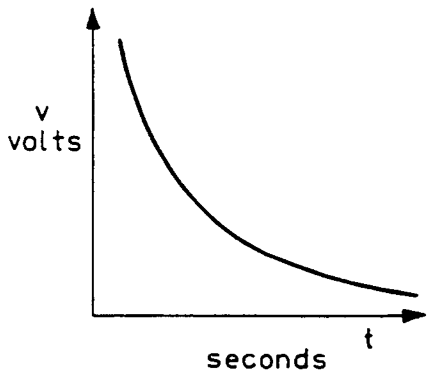


Fig 2.3

Q2.4 What effect will the capacitor C have on the output of the 150M when it is in sampling mode?

Q2.5 Why is the negative side of the capacitor in fig 2.1 connected to the -15V supply?

Practical 2.1 Use of Filters

Ensure that you have connected up the circuit of fig 2.4 as in the Preliminary Procedure.

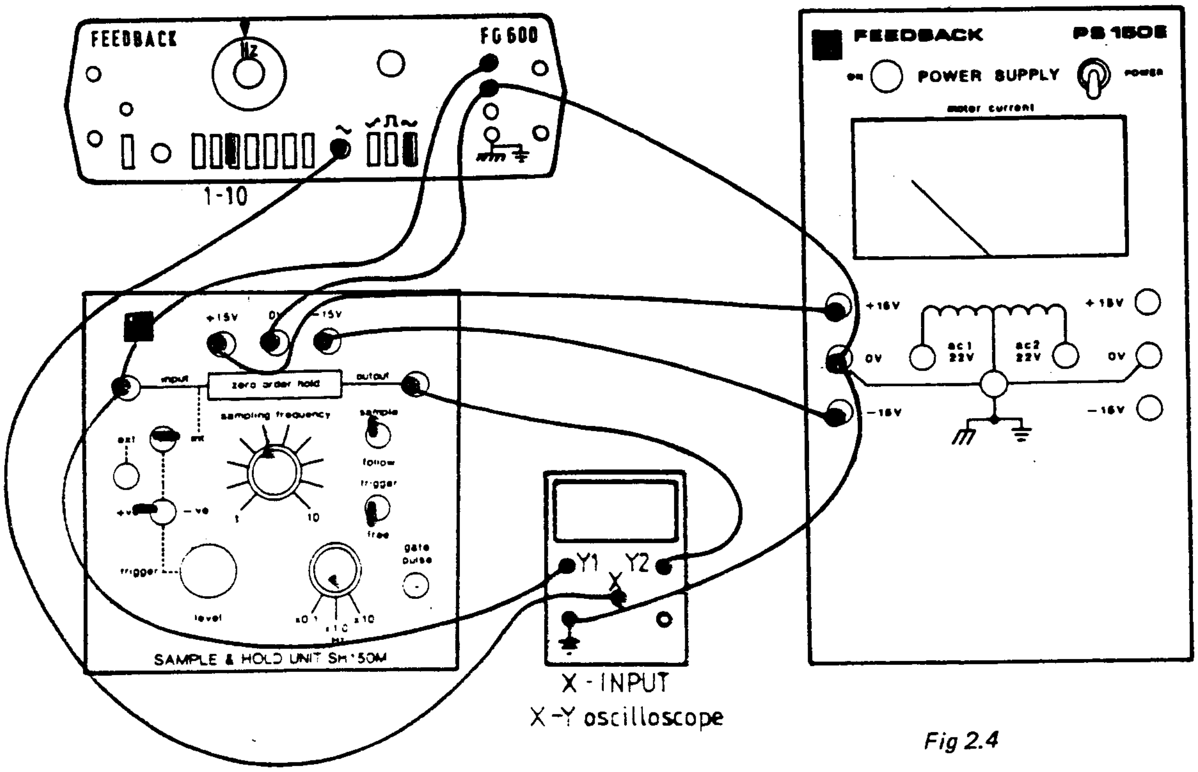


Fig 2.4

Now switch on and compare the output waveforms. Take a tracing of the waveforms on the oscilloscope screen.

Remove one of the capacitor leads for an instant so that you can make an immediate comparison with and without using a filter. Replace the lead.

Exercise 2.1

a) Taking the output in fig 2.5 (b) as the unfiltered output, calculate and plot the curves for the effect of the filter in a sampling period of 50Hz and refer to the information given in fig 2.1 for the time constants of the circuit.

b) What did you notice as you varied the sampling frequency control knob over its range? Using the plot of 2.1(a) explain why the output will appear sinusoidal when a filter is used.

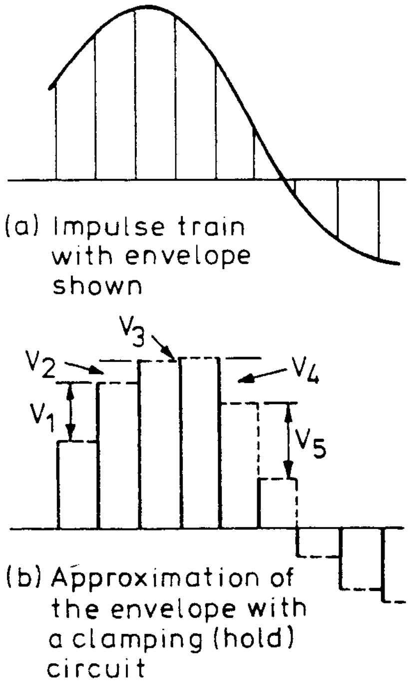


Fig 2.5

Now set the FG600 to a square waveform at 10Hz and the sampling frequency to 100Hz. Draw a tracing of the two waveforms on the oscilloscope screen.

Remove a capacitor lead so that you can see the effect of using a filter. Replace the lead. Reset the input frequency to 1Hz and vary the sampling frequency control over its range. Watch the oscilloscope carefully and note all changes.

Exercise 2.2

Explain why a high sampling rate is needed to recover the square waveform of the input.

Lastly set the FG600 to a triangular 10Hz waveform with a sampling rate of 100Hz. Draw a tracing of the two waveforms on the oscilloscope.

Remove a capacitor lead so that you can see the effect of filtering. Replace the lead.

Reset the FG600 to a 1Hz frequency output and vary the sampling frequency control over its range. Watch the waveforms carefully.

Exercise 2.3

Why with a lower sampling frequency will you get a sinusoidal output?

To complete this assignment on the way that we can use sampling of waveforms, we will carry out an experiment that will underline the principle of the sampling oscilloscope

Sampling oscilloscope

At very high frequencies, say over 100MHz, it is extremely difficult to design oscilloscopes that have a broad enough bandwidth to deal with such waveforms. The incorporation of sampling offers an effective solution to this problem. Taking the waveforms in fig 2.6(a), if this waveform is pulse sampled at a lower speed, that is at a fixed fraction of the input signal, then after a certain number of cycles the pulse will repeat the pattern of fig 2.6(b). This means that if we are unable to view directly the signal waveform then the sampled waveform will give us the shape of the signal.

The shape would be even more effective if we could just see the tips of the pulses so that they formed an envelope.

Practical 2.2 Use of sampling oscilloscopes

In this practical we shall use an oscilloscope with an external brightness control. This means that the beam can be made to flash brightly when it is pulsed. This pulsing will occur at the instant of sampling. The connections to make for the circuit are as in fig 2.7. The sweep control on the oscilloscope will externally trigger the 150M so that pulsing over each screen sweep will be synchronised with the sampling pulses. By using a trigger from the FG600 into the external trigger of the oscilloscope, the whole system becomes synchronised.

Using a triangular waveform the image seen on the oscilloscope screen will be as in fig 2.8. If n is the ratio of signal to sampling frequency then the pulses P will advance at a rate of 360 ÷ n° along the waveform.

Adjust the waveform to triangular 100Hz output and set the sampling frequency to 99Hz.

Switch on and make a tracing of the waveforms on the oscilloscope screen.

Exercise 2.4

Draw a block diagram of the essential parts of a sampling oscilloscope.

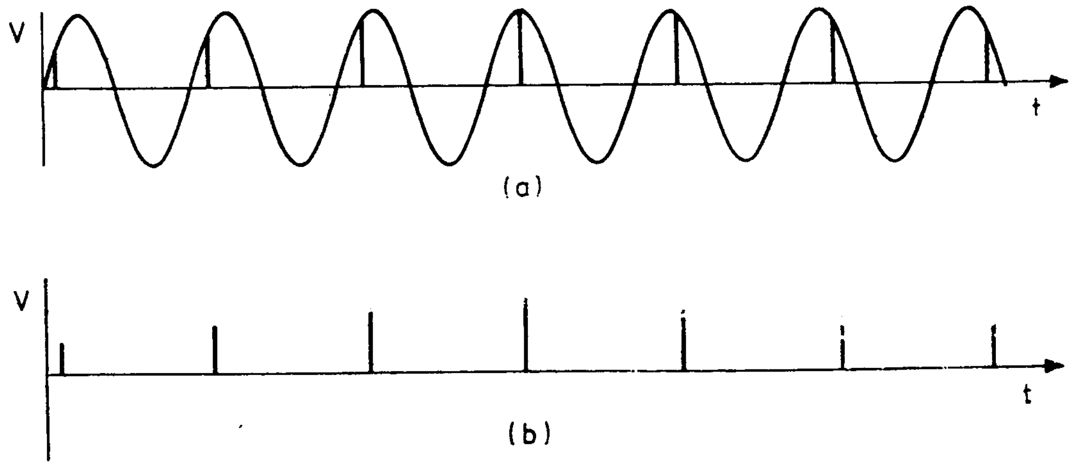


Fig 2.5

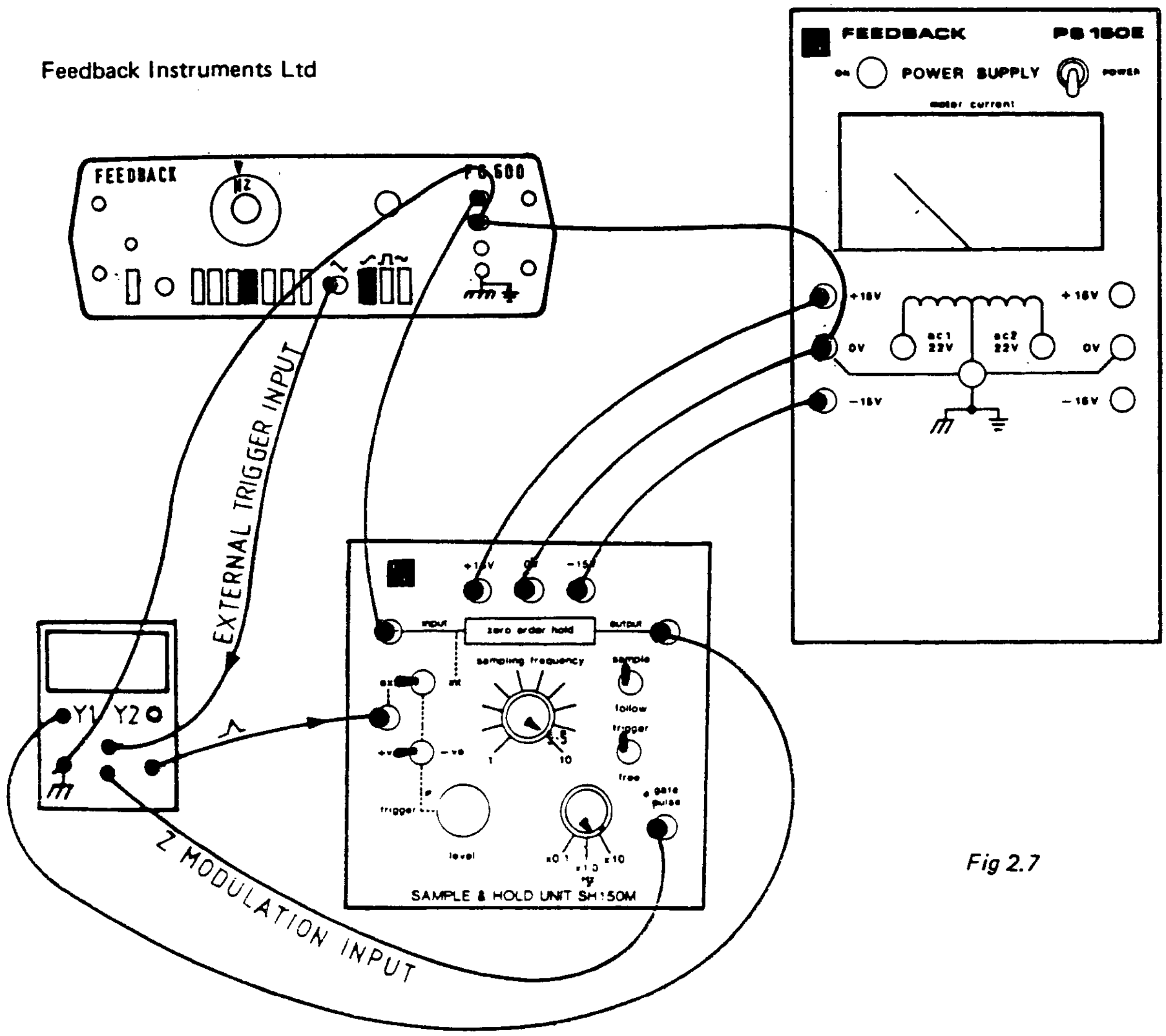


Fig 2.7

PRACTICAL CONSIDERATIONS AND APPLICATIONS

The use of sampling techniques has meant a very significant advance in the frequencies at which oscilloscopes can be used. As we have seen the CR tube X-Y controls using the principle of the stroboscope can study fast motion using a sampling pulse; an oscilloscope of relatively low-bandwidth can be used to build up a series of dots into the waveform of the incoming signal. The only limitation of this type of instrument is that only one sample is taken and displayed for each period of the signal. However, for waveforms having bandwidths of over 10GHz and with amplitudes of only a few mV, the sampling oscilloscope is the only means of viewing the signal.

A recent development has been to use the oscilloscope on a random sampler basis. Using random sampling where there is no fixed sampling rate leads to simplification of the circuitry, as no delay line or pre-trigger is needed.

A further development in the use of Sample/Hold circuits has been in systems using Pulse Code Modulation (PCM). In such a system the input is sampled and a binary word generated equivalent to the height of the sample. After serialising, the PCM words are transmitted using high frequency techniques. At the receiver each word is reformed into a pulse of a value equivalent to the original and is then maintained in a hold circuit till the next pulse is generated, as in fig 2.9.

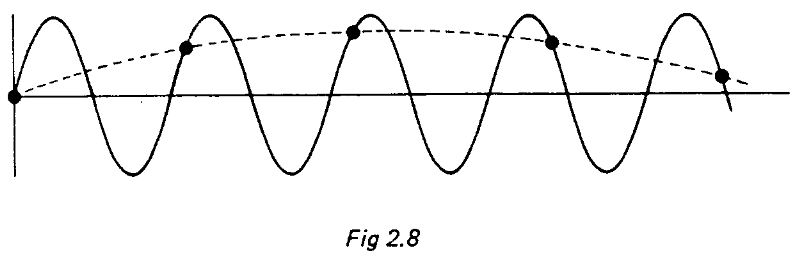


Fig 2.8

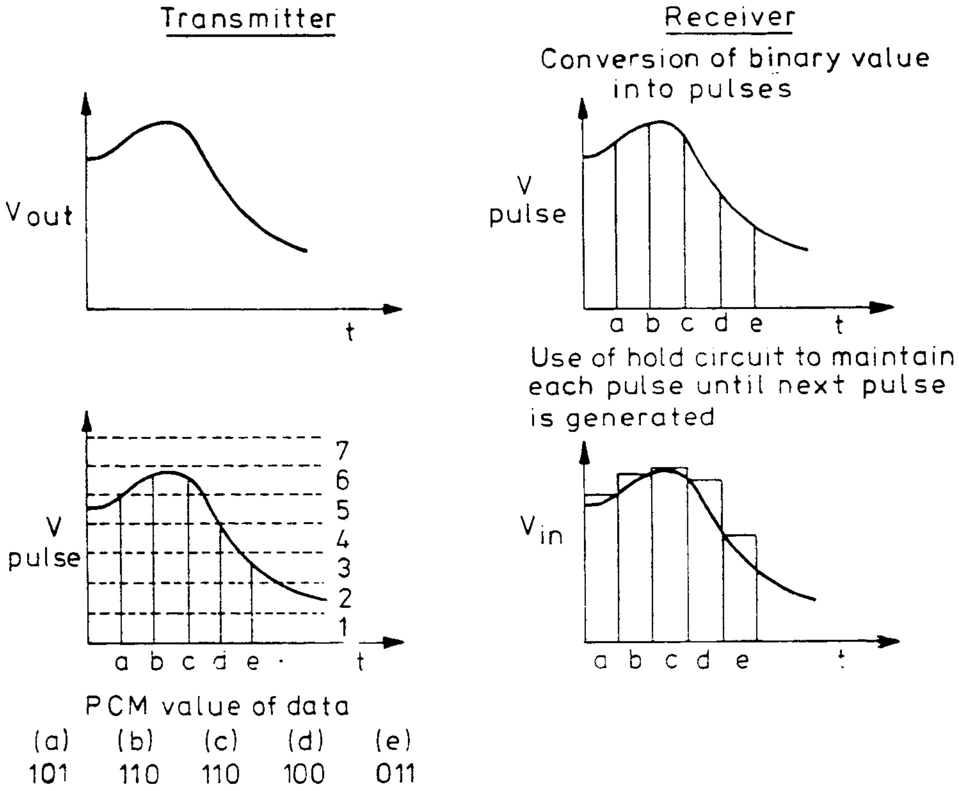

Transmitter
Receiver
Conversion of binary value into pulses
Vout
t
V pulse
a b c d e
t
Use of hold circuit to maintain each pulse until next pulse is generated
7
6
5
4
3
2
1
V pulse
Vin
a b c d e
t
PCM value of data
(a) (b) (c) (d) (e)
101 110 110 100 011

Fig 2.9

Object

Effect that the sampling rate has on the operation of a feedback Servomechanism when a Sample/Hold circuit is interposed in the error channel.

Equipment required

Quantity	Apparatus
1	Operational Unit 150A
1	Pre-Amplifier 150C
1	Servo Amplifier 150D
1	Power Supply 150E
1	Input Potentiometer 150H
1	Output Potentiometer 150K
1	Sample/Hold Module 150M
1	Dual-trace oscilloscope
1	FEEDBACK Function Generator FG600
1	Centre zero voltmeter
1	100kΩ resistor

Approximate time required

Two hours

Prerequisites

Kit 150M Assignments 1 and 2.

Kit MS150 D.C Basic Assignments in Control — Book 1, Assignments 1 to 5 and 7.

PRELIMINARY PROCEDURE

1. Interconnect the units forming fig 3.4.

2. Connect up the ±15V and 0V outputs on the Power Supply 150E to ±15V and 0V inputs on the Operational Unit 150A, Pre-Amplifier 150C, Servo Amplifier 150D, Input Pot 150H, Output Pot 150K and Sample/Hold 150M.

3. Connect the 8-way socket on the Power Supply 150E to Servo Amplifier 150D.

4. Connect the 8-way socket on the Servo Amplifier 150D to the Motor Unit 150F.

5. On the Sample/Hold 150M set the:-

Sample/Follow	to	FOLLOW
Trigger/Free	to	FREE
Ext/Int	to	INT
+ve/-ve	to	+ve
Frequency Multiplier	to	X10
Sampling Frequency	to	position 10

6. On the FEEDBACK Function Generator FG600 set the:

   Frequency range to 1-10Hz
   Frequency dial to 1
   Function switch to square waveform
   Output Amplitude to zero

7. On the dual-trace oscilloscope, set the:

Timebase	100ms/cm
Amplifiers Y_1 and Y_2	1V/cm

8. Set the Input Potentiometer 150H to 0°.

9. Set the Feedback Selector Switch on the Operational Unit 150A to resistive feedback.

Fix a 4mm plug onto one side of a spare 100kΩ resistor and place it into position 4 on the amplifier and the other side into the output of the Function Generator.

10. Connect the Power Supply 150E, Function Generator FG600 and Oscilloscope to the Mains outlets. DO NOT switch on yet.

DISCUSSION AND EXPERIMENTAL PROCEDURE

We have already seen in Assignments 1 and 2 that the great advantage of the Sample/Hold circuit is in its ability to maintain the level of a signal at a discrete level chosen by the sampling period.

The object of this assignment is to show how such a circuit can be used to control a series of servo mechanisms, set over a wide area, from a central point.

Whilst we could incorporate the Sample/Hold circuit in a system such as in fig 3.1, it would have the disadvantage that the actual state of each servomechanism was not known and so dangerous variations from the required state can occur. To overcome this, transducers can be fitted to the machines to monitor their actual performance with the information being relayed back to the signal source and then electronically compared with the required state. Now the control signal consists not of the required state but of the error value.

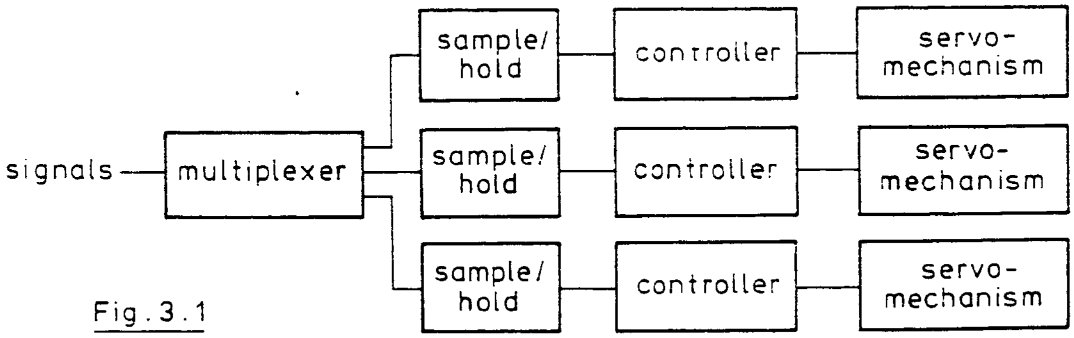


Fig.3.1

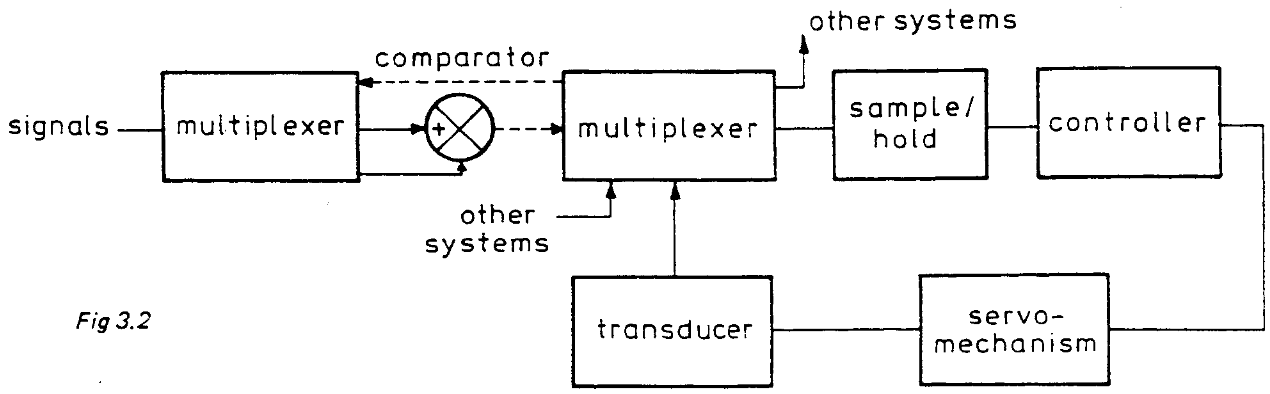


Fig 3.2

Q3.1 What do you notice about the positioning of the Sample/Hold circuit?

We have now moved the Sample/Hold circuit into the error channel so that it will maintain discrete signal values.

For the purpose of this assignment the machine to be controlled will be the DC Modular Servo System MS150 connected as a Position Control Servomechanism, having a schematic layout as in fig 3.3. In this assignment we will examine the effect on the system performance of interposing the Sample/Hold circuit in the error channel to simulate the type of condition we have been discussing.

It is more important for a proper understanding of this assignment that you have carefully read Section 1 to 5 of Part 1 of the MS150 Modular Servo Manual Book 3 and fully appreciate the principles of operation of a Position Control Feedback system using proportional and velocity control.

Exercise 3.1

Write an essay explaining the operation of a Position Control Feedback system, such as is shown in fig 3.3 but ignore the use of the Sample/Hold circuit and Function Generator. Explain how the Operational Amplifier produces an error channel; the use of the Pre and Servo Amplifiers; how feedback from the Output Rotary Pot produces proportional control and using the Tachogenerator produces velocity control. Deal with the transient response of the system and how overshoot occurs.

Q3.2 If the input potentiometer is connected to ±15V supplies and has a range of 300°, what rotation of the potentiometer would give an output of 3 volts?

Now in this assignment we are not going to rotate manually the input potentiometer by 30° to give an output of 3 volts but use the output of the FG600 Function Generator to simulate the effect of having a remote signal source. By this means we can control accurately the speed and way in which we wish to create this input, because we can do it suddenly with a square waveform or gradually with a sinusoidal waveform.

Setting up the Servomechanism

Ensure that you have connected up the circuit of fig 3.4 as set out in the Preliminary Procedure.

Check that the MS150M Sample/Hold is set to FOLLOW and the FG600 Function Generator is set to a square wave output at a frequency of 1Hz but that the output amplitude is set to zero.

Before starting the assignment it will be necessary to zero set the Operational Unit 150A and Pre-Amplifier 150C as well as ensuring that the rotary potentiometers are properly adjusted.

The Basic Assignments on Control manual (Book 1) gives full details of how to carry out these procedures and the assignments that give the information are listed under PREREQUISITES on the front page of this assignment.

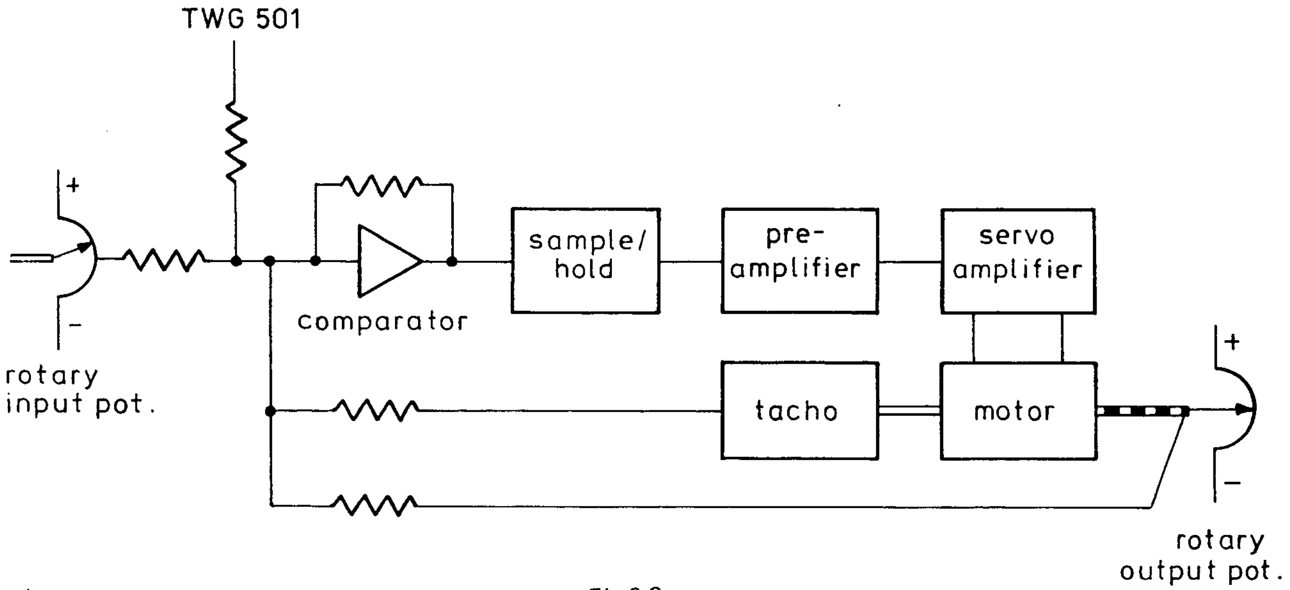


Fig 3.3

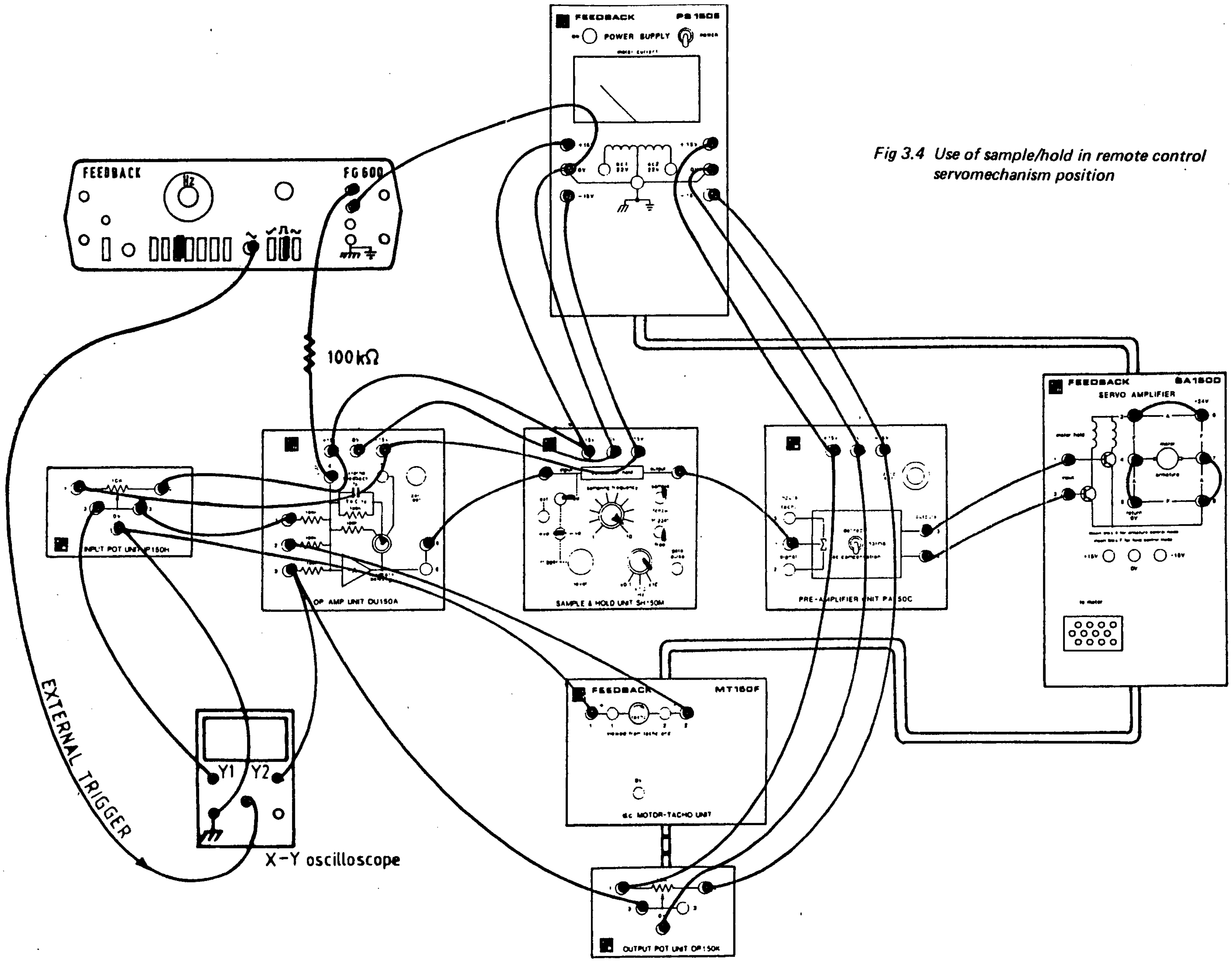


Fig 3.4 Use of sample/hold in remote control servomechanism position

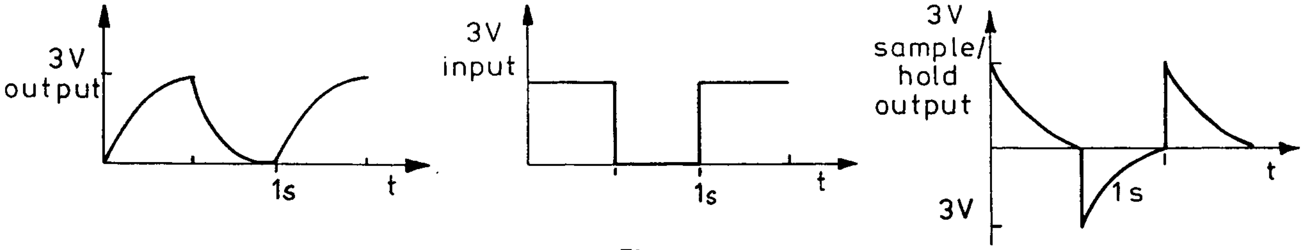


Fig 3.5

Practical 3.1 Operation of the system
Switch on the Oscilloscope and Function Generator. Set the Generator's output to 3 volts.

Make a tracing of the waveforms appearing on the oscilloscope screen.

Q3.3 Did your observations agree with those shown in fig 3.5?

Now set the Sample/Follow switch to Sample on the Sample/Hold unit.

Make a tracing of the waveform appearing on the oscilloscope screen.

Q3.4 Is there any change in the waveforms from fig 3.5?

Q3.5 Why is there no change in the appearance of the waveforms?

Sampling at 100Hz with an input of 1Hz will virtually rebuild the shape of the required error signal, so there should not be any change.

Q3.6 Why is the transient response of the system important in determining the response to types of input signals of varying frequencies?

The transient response shows the delays in time between an error output value and the motor running at the speed required by the value of this signal. So that if the motor is unable to respond fast enough to changes in error values, overshoot will occur and the degree to which these are damped gives an indication of the stability of the system. The time taken for the output to settle is therefore the minimum period for a system to be input.

Q3.7 In what way can reduction of sampling rate affect the system response?

For a good control there must be a smooth change in error value as the output nears alignment. If the sampling time intervals and consequent error value changes may be too great, then the output will not smoothly come to a halt but will overshoot and oscillate about the point of alignment. Instability can also occur if the sampling intervals become too great in to the approach speed of the output and the point of alignment.

On the Function Generator change the variable control to give a sinusoidal waveform output at a frequency of 2Hz. Then slowly reduce the sampling rate from 100Hz to 0.5Hz, noting what happens to the behaviour of the Output Pot and the waveforms on the oscilloscope screen. At 16Hz, 4Hz and 0.5Hz sampling rates, make tracings of the waveforms on the screen and note for each set what is happening to the indicator on the Output Pot.

Exercise 3.2

Explain the reason for the behaviour of the Output Pot indicator together with the waveforms appearing on the oscilloscope screen over the sampling range of 100Hz to 0.5Hz with a sinusoidal input of 2Hz. If the indicator rotates, explain the reason with diagrams.

Reset the sampling frequency of the Sample/Hold circuit to 100Hz and change the variable control on the Function Generator to give a square waveform output at the same frequency of 2Hz.

Connect the Y_1 input to the oscilloscope to the PULSE output of the Sample/Hold circuit and adjust the sampling rate to give a response as in fig 3.6.

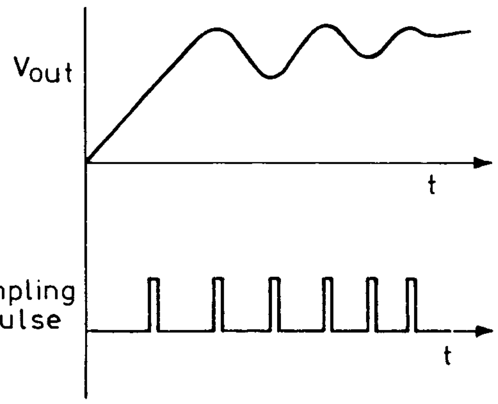


Fig 3.6

Slowly reduce the sampling frequency until the system becomes unstable.

Exercise 3.3

Explain what happens as you reduce the sampling frequency and why, in the end, the indicator rotates.

Exercise 3.4

Draw a design for a two-servo system having a common error channel interposed between the Operational Amplifiers and the Pre-Amplifiers. If the servos have a simple lag type frequency response with bandwidths of 1Hz and 2Hz respectively, state what sampling frequency you would use.

PRACTICAL CONSIDERATIONS AND APPLICATIONS

The use of computers to control industrial processes has meant that many machines set out over a wide area can be controlled in a very sophisticated manner from a central point. Very often the machine itself will have several parameters that have to be controlled, such as a numerically controlled magazine-fed multi-tool machine.

A computer has the great advantage that it is able to make calculations at great speed and store information in the form of programmed instructions and reference data and then process the data under the direction of a controller, as in fig 3.7.

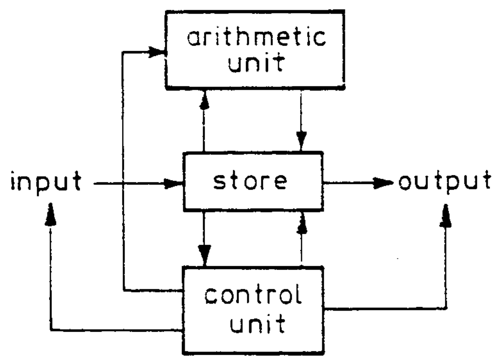


Fig 3.7

In this way programs of instructions can be written that will control the operation of each machine in the system, to take account of all operating conditions and problems. The operating state of the machine being controlled is then input into the computer and this information then becomes data forming part of a series of calculations that will form the new error state. So that now the comparator and signals from the Input Pot or Function Generator output that helped to form the error channel in this assignment, are incorporated into the computer. As a fast computer can undertake a string of instructions with calculations in a few milliseconds, either a large number of machines can be controlled or the computer can carry out other jobs such as processing accounts, etc and then be interrupted at each sampling interval to receive information on the state of the machine, and calculate the error value which is then output to the Sample/Hold input of the machine system. The triggering on the Sample/Hold can be used to synchronise the sampling pulse to the output from the computer.

If however, a number of systems are to be controlled then the sampling frequency will decide the number that can form part of any process control system. Each machine will need to receive signals giving changes in error value that are sufficiently rapid for there to be a smooth response. A balance, therefore, has to be struck between an economic utilisation of the process controller and acceptable performance by each machine in the system that is based on a sampling rate that allows a reliable feedback signal to be processed by the computer.

Object

To examine the use of sampling techniques in the error channel of a simulated integral control system.

Equipment required

Quantity	Apparatus
1	Power Supply MS150E
1	Sample/Hold SH150M
1	Process Control Simulator PCS327
1	Function Generator FEEDBACK FG600
1	Oscilloscope

Approximate time required

Two hours

Prerequisites

Experiments 1, 2, 3, 4 and 5 in Manual PCS327.

Kit 150M Assignments 1, 2 and 3.

PRELIMINARY PROCEDURE

1. Interconnect the Process Control Simulator PCS327 to the Sample/Hold SH150M as in fig 4.2.
2. Patch the front panel of the PCS327 as in fig 4.3. Set the controls to:

   Proportional band to 50%
   Set Value to zero
   Lag/Integ to INTEG
   Fast/Slow Process to SLOW

3. Connect the ±15V and COM outputs on the Power Supply PS150E to the ±15V and COM inputs on the 150M.
4. Set the controls on the 150E to:-

Sample/Follow	to	FOLLOW
+ve/-ve	to	+ve
Ext/Int	to	EXT
Trigger/Free	to	FREE
Sampling frequency	to	10
Frequency range	to	X1

5. Connect the Function Generator FG600 main square wave output to the PCS327 input and triangular wave output to the oscilloscope input as shown in fig 4.2. Set the controls to:

   Function switch to square waveform output
   Frequency range from 0.01 to 0.1Hz
   Frequency dial to 3

6. Connect the Y input on the Oscilloscope to the PCS327 output. Set the amplifier amplification to 5V/cm.
7. Connect the Mains plugs on the 150E, PCS327, FG600 and Oscilloscope to their respective Mains socket. DO NOT switch on.

DISCUSSION AND EXPERIMENTAL OCEDURE

In complete systems such as automatically operated chemical plants, oil refineries, paper mills, etc; masses of liquids and gases are continuously in movement and subject to process at various temperatures and pressures. During movement of the liquid and gas, pumps must be used to maintain pressure, heaters to set the temperature and valves to control the rate of flow.

Q4.1 In what way can Sample/Hold circuits be used in such systems?

Such coupled system will use a large number of valves, pumps and heating elements. There will be a complex interaction between these controllers, for optimum operation of the whole system, the state of each part of the system will need to be referenced back at suitable time intervals to a central source so that calculations may be made to see if alterations are needed in the settings of the controllers. If a system is to operate using a common error channel then the advantages brought out in Assignment 3 of using Sample/Hold circuits will also apply in such systems.

Q4.2 In what way would the use of a Sample/Hold circuit be an advantage in such an Automatic Process Controlled system using a common deviation channel?

As each Controller in the system will be connected to the error channel for only a fraction of time, the Hold facility can be used to maintain a driving signal during the time interval the Controller is not connected to comparator.

Q4.3 What are the uses and advantages of using the Process Control Simulator PCS327 when modelling the Controllers of a Process Control System?

The advantage of the PCS327 is that we can build up a simulation of a Controller so that it operates according to a combination of states and terms that we require.

Q4.4 With integral control the output signal of the system will change at a rate proportional to the time integral of the deviation.

So that if θ = deviation
θ_c = output signal
K = system gain

then $\frac{d\theta_c}{dt} = K\theta$

or $\theta_c = -K\int\theta.dt$

It is from this equation that the control action derives its name.

Q4.5 What effect does integral control have on the performance of a Controller?

Using integral control the steady state deviation of the system will be reduced to zero because there will be an output response as long as there is a deviation.

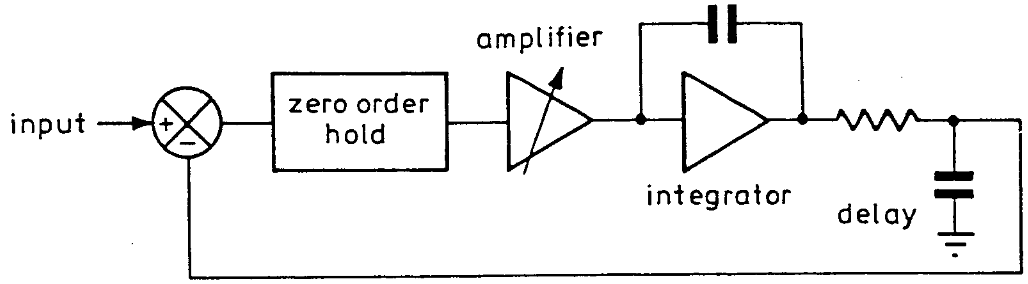


Fig 4.1

Practical 4.1 Sampling techniques with Process Controller

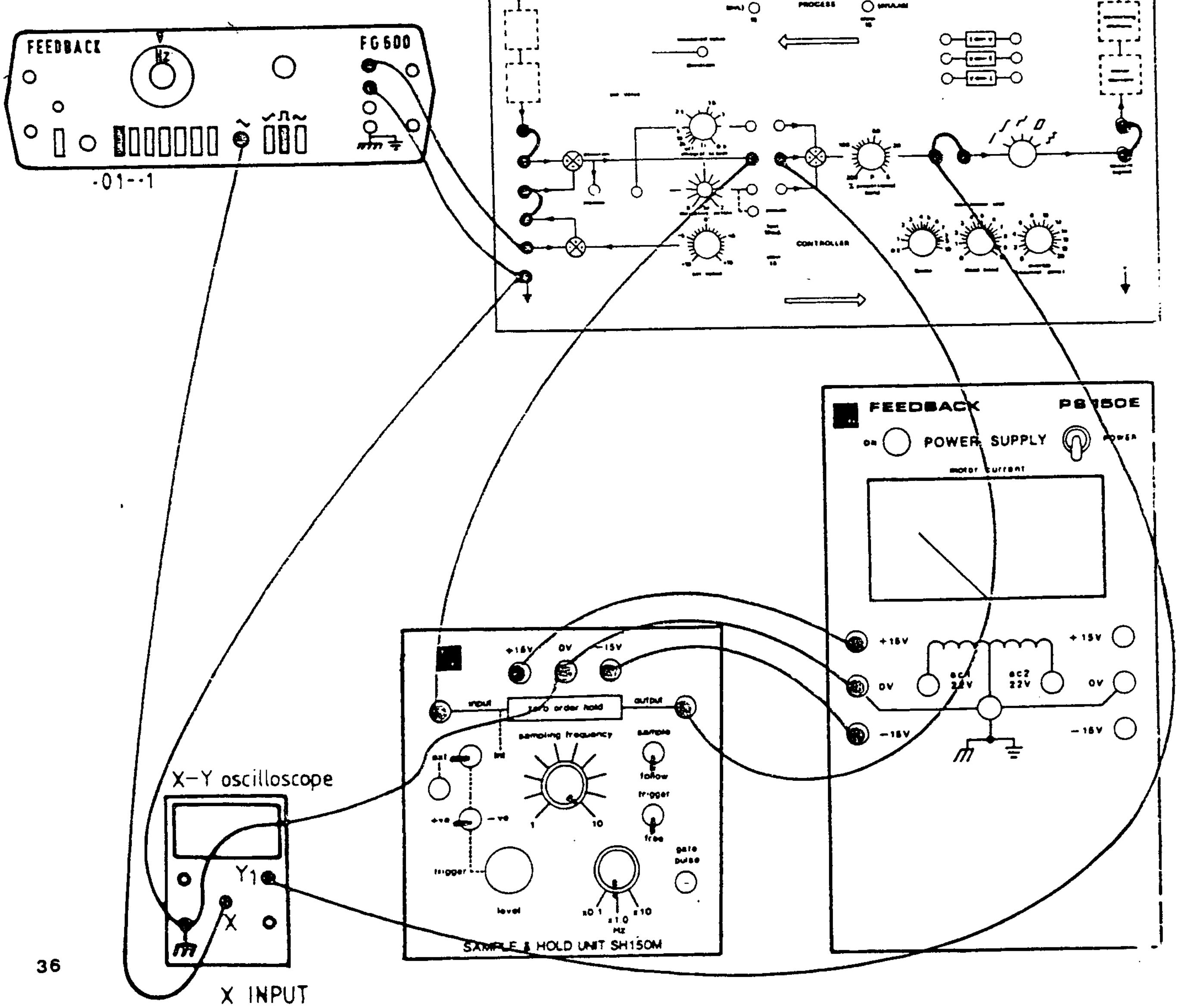
Fig 4.1 shows in block form the elements needed to simulate a Controller using integral feedback control including the Sample/Hold in the error channel.

Connect up the Process Control system according to the instructions given in the Preliminary Procedure.

Q4.6 Why does the front panel patching of the PCS327 include an inverter and delay?

As the integrator is in the feedback path of the system, an inverter has to be used to ensure an odd number of inversions so that the feedback is negative. The time between a signal being input and the system responding is simulated by the delay.

Fig 4.2 Examination of simulated sampled data control system



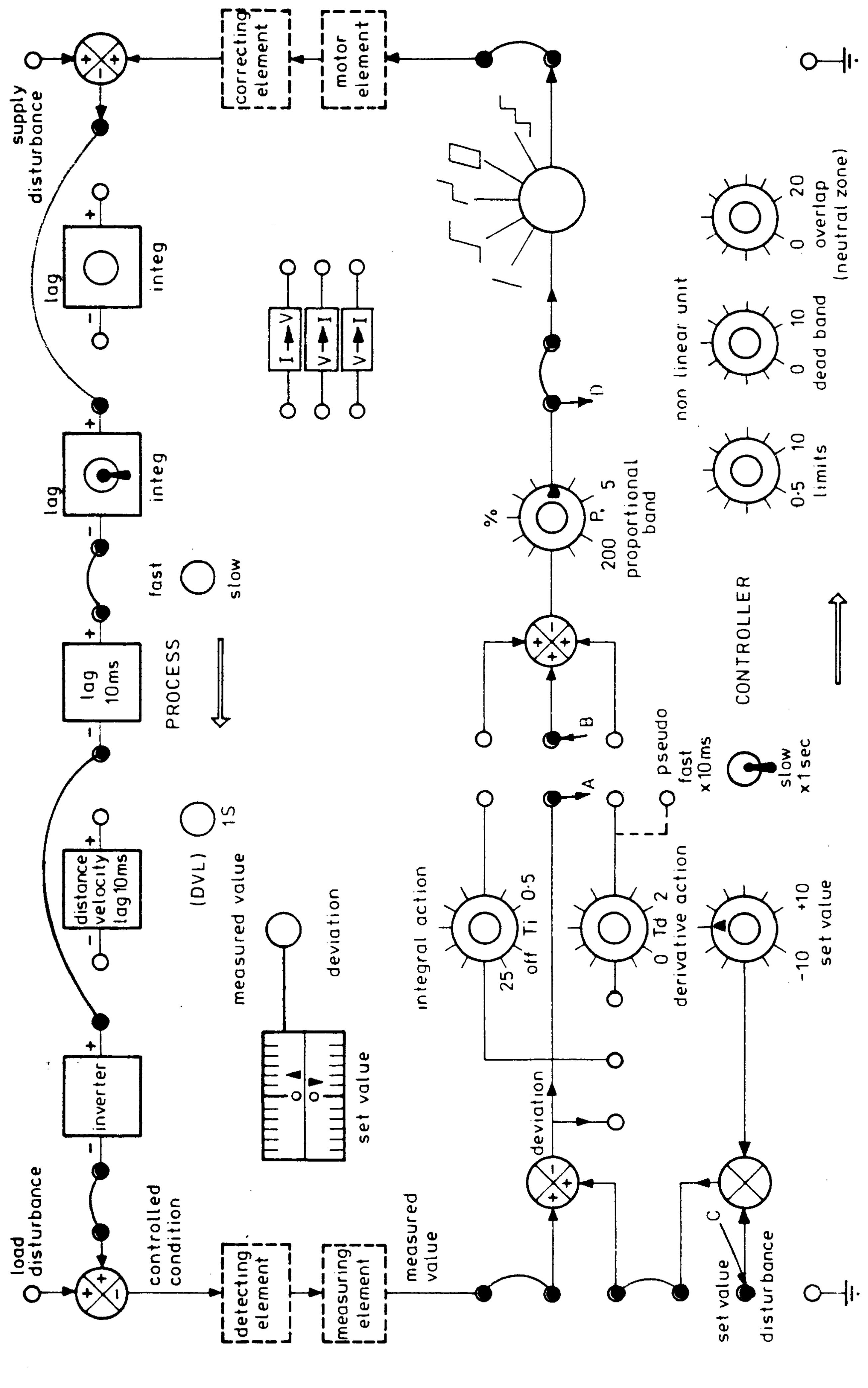

load disturbance
controlled condition
detecting element
measuring element
measured value
inverter
distance velocity lag 10ms
(DVL)
1S
lag 10ms
PROCESS
fast
slow
lag
integ
lag
integ
supply disturbance
correcting element
motor element
measured value
deviation
set value
I→V
V→I
V→I
deviation
integral action
25
off
Ti
0·5
derivative action
0
Td
2
set value
-10
+10
A
B
C
D
pseudo
fast x10ms
slow x1sec
%
200
P.
5
proportional band
CONTROLLER
non linear unit
0·5
10
limits
0
10
dead band
0
20
overlap (neutral zone)
set value
disturbance

Fig 4.3

Switch on the 150E, PCS327, FG600 and the Oscilloscope.

Q4.7 Is the output waveform on the oscilloscope screen the same as in fig 4.4?

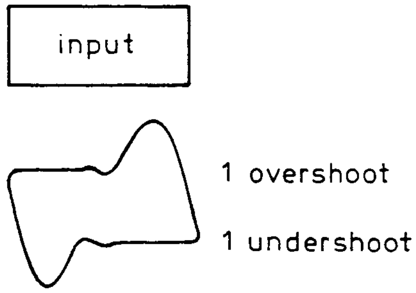


Fig 4.4

Now change the Follow/Sample switch to SAMPLE.

Q4.8 Has there been any change in the output waveform shown on the oscilloscope screen, when changing from Follow to Sample on the Sample/Hold circuit?

Changing the switch on the 150M to SAMPLE will not, with an input of 0.03Hz and sampling rate of 10Hz, alter the shape of the output waveform.

Q4.9 Why does the output waveform remain the same?

As we saw in Assignment 3, when the sampling period is very small in comparison with the input signal, changes in the value of the deviation will be reproduced by the Sample/Hold circuit without noticeable degradation of the required output driving signal. In this case the sampling period is 1/333 of the input signal and so is very small.

Exercise 4.1

Explain, using the observations made in Assignment 3, what you would expect to happen to the output waveform, if the sampling frequency was gradually reduced to 0.3Hz. How would reducing the system gain affect the output waveform?

Now reduce the sampling frequency to 3Hz and then 1Hz. On each occasion make a tracing of the waveform and output on the oscilloscope screen.

Q4.10 How oscillatory did the output become, as the sampling frequency was reduced?

The number of overshoots and undershoots will increase as the frequency of sampling is reduced.

Alter the proportional band control to 200%.

Q4.11 How will this affect the gain of the system?

By increasing the proportional band control from 50% to 200% the gain is reduced to a quarter of its previous value.

Reduce the sampling frequency to 0.3Hz and make a further tracing of the waveform output on the oscilloscope screen.

Exercise 4.2

Using the explanation given in exercise 4.1, relate the output effect shown by a sampling frequency of 3Hz and 1Hz with proportional band control of 50% to a 0.3Hz sampling frequency and proportional band control of 200%. What will be the frequency of the oscillatory signal superimposed on the steady state response of the output?

Exercise 4.3

Fig 4.5 shows the transfer functions of each item in the system used in this assignment.

The loop gain expressed as a transfer function is:

$$\frac{X_1(s)}{E(s)} = \frac{1-e^{-sT}}{s}\;\frac{1}{sT_1}\;\frac{A}{1+sT_2}$$

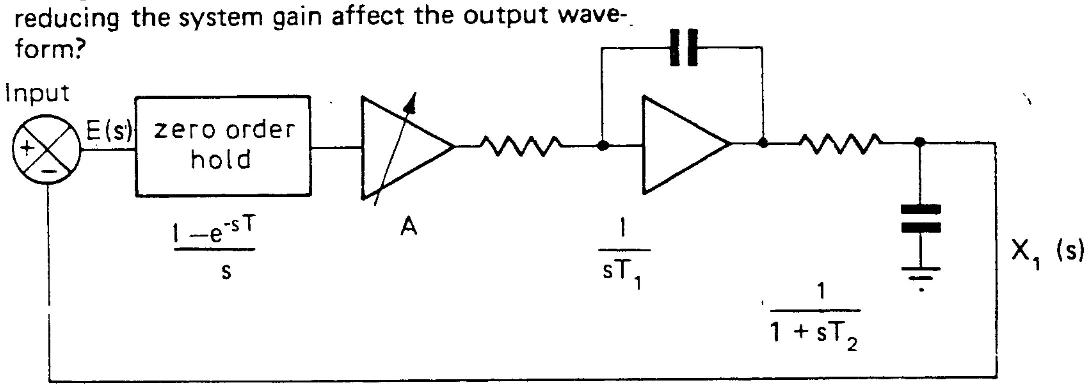


Fig 4.5

Show that the corresponding z-transform is

$$\frac{X_1(z)}{E} = \frac{A_1\ (z_1 - z_2)}{(z-1)\ (z - z_\beta)}$$

where $z_\beta = e^{-\beta}$ and $\beta = T/T_2$.

PRACTICAL CONSIDERATIONS AND APPLICATIONS

Continuous process plants, such as chemical, petroleum refining plants, etc. have been in the fore-front of those industries using automatic control. Usually the power to operate the Controllers has been hydraulic or pneumatic. Such sources of power have not lent themselves to centralised control as a way of achieving optimum operating conditions. The incentive to introduce central process control has already been there as a way of increasing the economic return of the plant, and the development of the computer has provided a means by which this can be achieved.

As an example, let us take a simplified block diagram (fig 4.6) of a petroleum refinery.

To optimise the income on a certain type of crude oil an output split of 70% petrol, 20% tar and 10% gas is needed. This can only be achieved if every part of the plant is operating at the correct temperature, pressure and rate of flow. With flow rates of many tons an hour any one part not operating at set conditions would affect every other part of the plant; only a central process control could safely run the plant to yield the best return.

The use allows for the control of hundreds of elements that form part of a complex plant.

In such situations Sample/Hold circuits are the only way in which each element would time share its error channel with all the other elements in the system.

This assignment has dealt with the use of Sample/Hold circuits for Controllers. Assignment 5 will deal with the use of these circuits where a process is being carried out, such as in the Reactor of a Chemical Plant.

Further Reading

Automatic Control Systems. D.C. Kuo (Prentice Hall)
On transfer function of hold circuits pp. 374-5.
On gain, damping, etc. pp. 360 et seq.

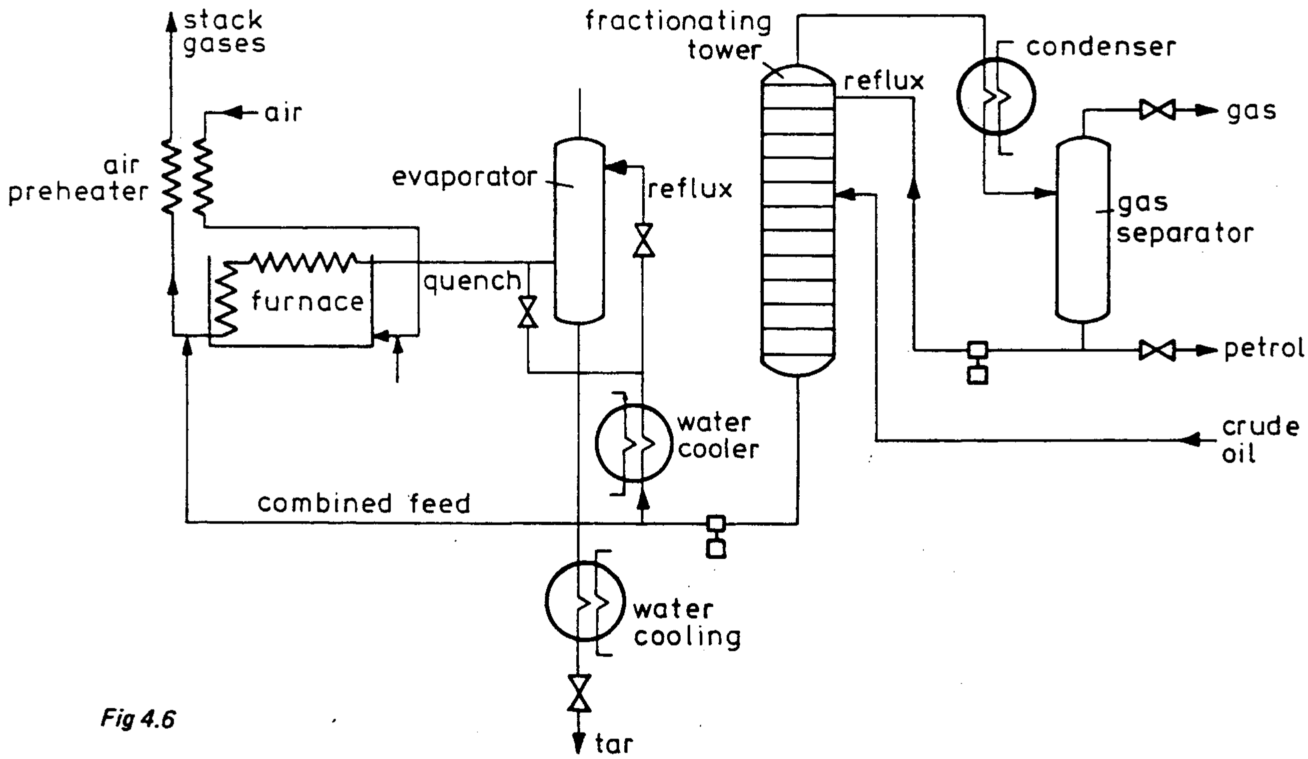


Fig 4.6

Object

To investigate the effects on the output of a process control system of interposing a Sample/Hold circuit in the error channel.

Equipment required

Quantity	Apparatus
1	Power Supply MS150E
1	Sample/Hold SH150M
1	Process Trainer PT326
1	Function Generator FEEDBACK FG600
1	Oscilloscope

Approximate time required

Two hours

Prerequisites

Assignments 1, 3 and 4.

Process Training Manual PT326. Experiments 1, 2, 3, 5 and 6.

PRELIMINARY PROCEDURE

1. Interconnect the Sample/Hold SH150M, Function Generator FG600 and Oscilloscope to the Process Trainer PT326 as in fig 5.2.

2. Connect the ±15V and 0V outputs of the Power Supply MS150E to the ±15V and 0V inputs of the Sample/Hold SH150M.

3. Set the Sample/Hold SH150M controls as follows:-

Sample/Follow	to	FOLLOW
Trigger/Free	to	FREE
+ve/-ve	to	+ve
Ext/Int	to	EXT

Set the sampling range switch to X1.

Set the sampling frequency to 10.

4. On the Process Trainer PT326:-

Patch the front panel as in fig 5.2.

Adjust SET VALUE to 40°C.

Adjust the BLOWER INLET to 40°.

Place the DETECTOR PROBE in 11″ position.

5. On the Function Generator FG600:

Set the Function switch to square waveform.

Set the Output Amplitude to 5V peak-to-peak.

Set the Frequency Range switch to 0.1 to 1.0 Hz.

Set the Frequency dial to 1.

6. On the oscilloscope set the amplifier to 5V/cm.

7. Connect the Mains plugs on the MS150E, PT326, FG600 and Oscilloscope to the Mains outlets. DO NOT switch on yet.

DISCUSSION AND EXPERIMENTAL PROCEDURE

In Assignment 4 we examined some of the reasons that make Sample/Hold circuits necessary in complex Process Control systems.

Q5.1 What principles of sampling techniques are there that can be demonstrated by making a hybrid experiment using the Process Trainer PT326 and Sample/Hold SH150M?

The elements forming the PT326 can be interconnected so that they can produce a physical change. This change consists in raising the temperature of air flowing in a process tube. During its flow the air will lose heat and a transducer will record this actual value at the other end of the tube. Various control systems can then be formed to control the behaviour of the air. While the PT326 gives the example of an air flow, for a control system we can take the Process to represent the rate at which a chemical reaction proceeds, the level of a liquid in a tank, etc. Because we can choose the types of elements to form the system, a full knowledge of each specific type of process control system can be obtained. Together with the Process Control Simulator PCS327, we can model the behaviour of any complex Process Control system. Whilst the PCS327 showed how different types of Controllers operate, the PT326 deals with the actual process.

For such systems to be centrally controlled the settings of the Process have to be optimised with that of the Controllers forming the systems. A common error channel will be required with each control in the Process and on the Controllers time sharing their use of the Comparators. The Sample/Hold circuit connected into each error channel, then maintains the deviation value whilst the channel is connected to the comparator and prevents degradation of the signal by sampling.

Exercise 5.1

Write an essay explaining:-

a) The difference between distance/velocity lag and transfer lag.

b) The difference between two step and continuous control.

c) The meaning of disturbance and system response to continuous control.

Practical 5.1 Using Sampling in a Process Control System

As in Assignment 4 we can only show the behaviour of a single variable, the temperature of the Process, and this is shown in block diagram form in fig 5.1.

Ensure that you have interconnected the units and made the connections on the Process Trainer as well as set the controls as shown in fig 5.2.

Switch on the units and the oscilloscope.

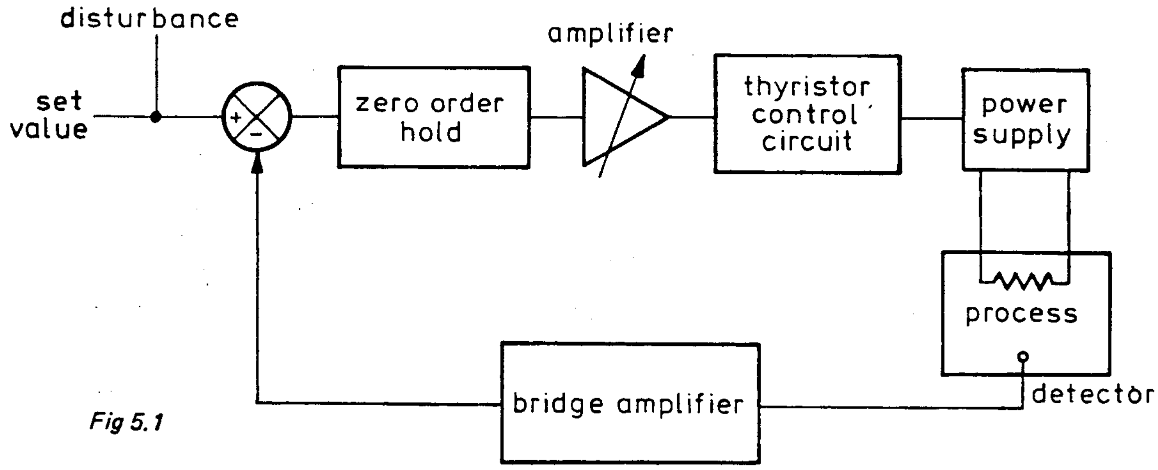


Fig 5.1

Exercise 5.2

Explain why you should have an output response shown on the oscilloscope, as in fig 5.3.

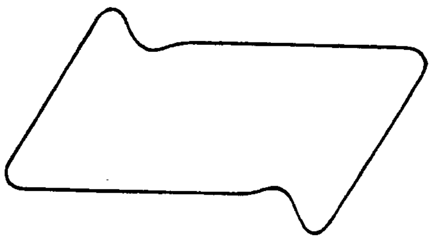


Fig 5.3

Now set the Sample/Hold SH150M to SAMPLE.

Exercise 5.3

Explain the output response that you now obtain on the oscilloscope.

Reduce the sampling frequency to 0.5Hz. Observe the output response shown on the oscilloscope.

Exercise 5.4

Explain why with a sampling frequency of 0.5Hz the output response becomes unstable. Can you obtain any relationship between the instability frequency and the sampling frequency.

Q5.2 What would you consider a satisfactory output response of the Process Trainer?

For a satisfactory response we must try to obtain a response as near as possible to that obtained when the Sample/Hold was set to FOLLOW.

Q5.3 How much overshoot and undershoot would you then tolerate.

With the Sample/Hold in FOLLOW there was one overshoot and one undershoot.

Exercise 5.5

State the minimum sampling frequency at which you consider the system performance to become satisfactory. Give your reasons why the performance has become satisfactory at this sampling frequency.

PRACTICAL CONSIDERATIONS AND APPLICATIONS

This assignment has dealt with the use of the Sample/Hold circuit when forming part of the forward control path, controlling the temperature of a mass of moving air. We have already discussed the part that Sample/Hold techniques play in the effective operation of industrial processes using a central process controller.

With this technique one monitoring and control system can be connected to a number of furnaces or reactors to analyse the atmosphere above the melt, or the characteristics of the gasified product. For simplicity a thermostat has been used to measure the temperature of the air. However with the use of infra-red techniques the proportion of CO, CO_2, SO_2, NH_3 and a large number of hydro-carbon and other gases in the stream can be measured by the highly characteristic spectra of each particular type of gas. By making these measurements at periodic intervals below the response time of the furnaces or reactors, a very sophisticated technique becomes available for controlling the purity of the final product.

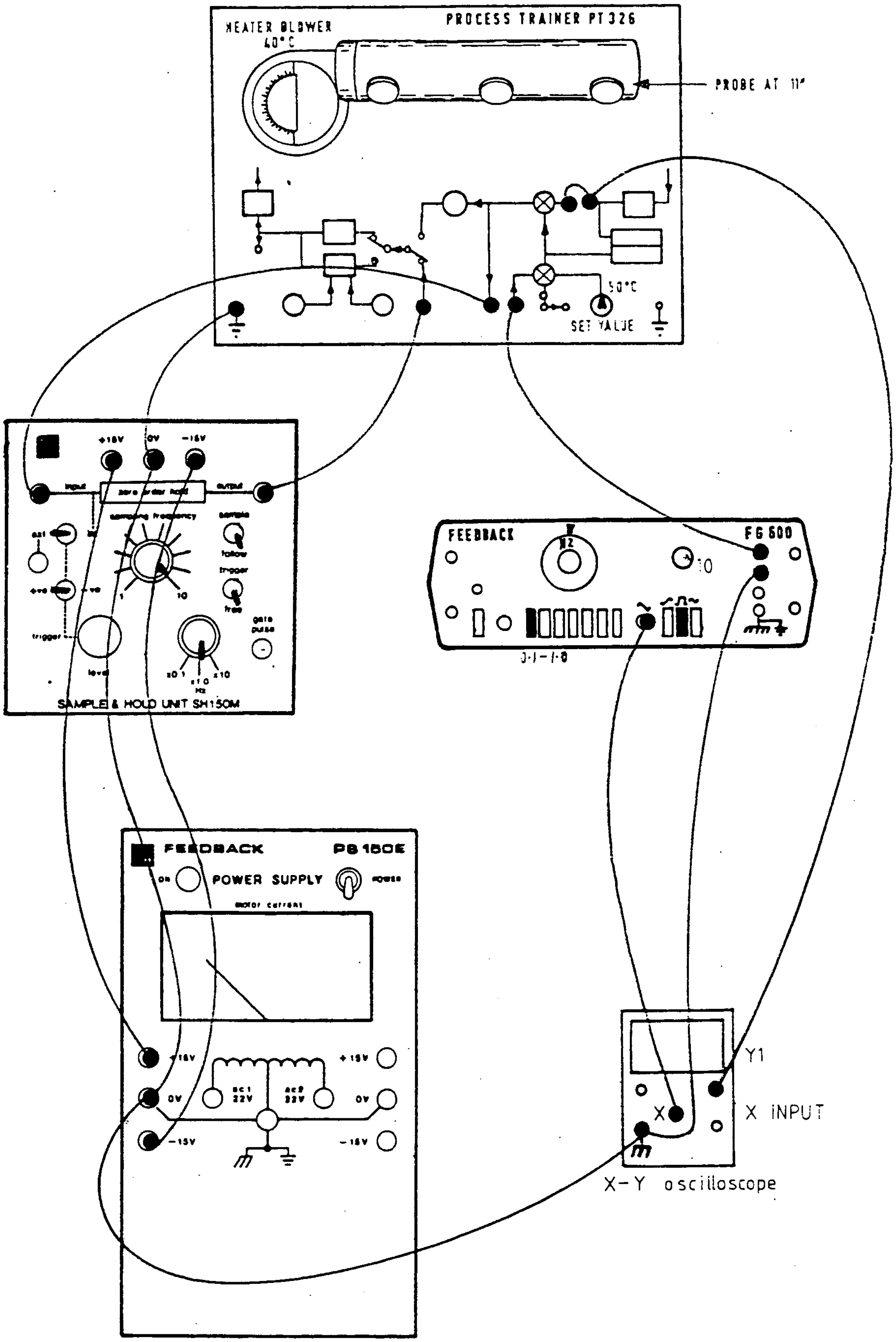


Fig 5.2 Use of sampling techniques in a process control system

APPENDIX 1

Transfer Functions of Hold Circuits in Sampling Systems

A normal way of establishing the characteristics of a discrete data sampling system using a hold circuit, is through its input-output relationship. The equations that are then derived can be expressed in terms of time (t). The hold circuit turns each sampled value into a pulse, having a period equal to the sampling period and with the input pulse related to the output by a constant delay interval T. To analyse the transfer function we can break the pulse, fig A1.1 into a Fourier series. To manipulate the resulting equations, we need to reduce them to an algebraic form, but if Fourier transforms are used there is the problem that the function must converge.

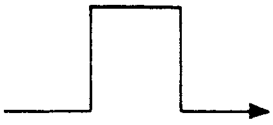


Fig A1.1

The Laplace Transform

The Laplace transform can overcome this convergency problem by taking the starting time of t = 0 so that if (T) is the known function of t for values of t > 0 then the Laplace transform L(s) of f(T) is defined as

$$L(s) = \int_c^{\infty} e^{-Ts} f(T).dt$$

In the cases we will be dealing with, s will be a complex variable whose real part is sufficiently large to make the integral in the equation convergent.

a) Transfer function of a zero order hold circuit

In fig A1.2 the zero-order hold circuit has an input, consisting of a train of unit pulses of amplitude V_o, related to the output by a constant delay interval T. The output may then be regarded as the sum of two step functions, as in fig A1.3 (a) and (b).

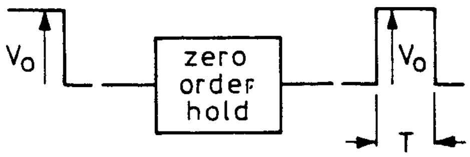


Fig A1.2

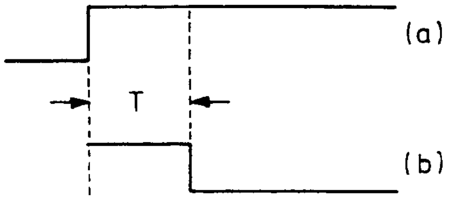


Fig A1.3

Expressed as Laplace transforms.

$$L(a) = \frac{1}{s}$$

$$L(b) = \frac{1}{s} e^{-sT}$$ where e^{-sT} is the delay factor

$$\therefore \text{Output} = \frac{1}{s} - \frac{1}{s} . e^{-sT} = \frac{1 - e^{-sT}}{s}$$

b) Transfer function of a first-order hold circuit

With a first-order hold circuit the form of the output response will be as in fig A1.4.

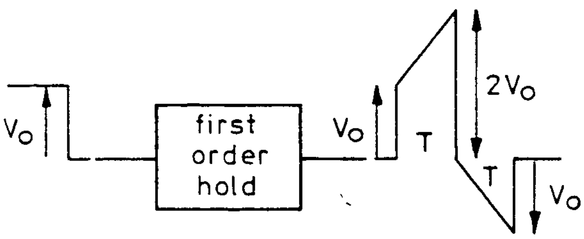


Fig A1.4

Developing the method used for the zero-order circuit, will give an output of

$$\text{output} = \left(\frac{1 + Ts}{Ts^2}\right) \left(1 - e^{-sT}\right)^2$$

The Z-Transform

When using Laplace transforms to obtain the transfer function for the hold circuit, the exponential term e^{-sT} will produce non-algebraic functions in the equations produced when analysing discrete data systems. A convenient way of overcoming this difficulty is by making

$$z = e^{sT}$$

A detailed description of the z-transform is beyond the scope of this appendix. However, in brief terms, for a hold circuit the transfer function expressed as a z-transform, can be calculated for given parameters. The method involves the use of root locus techniques to establish conditions under which the system will be stable. The plots, however, are made in the z-plane and if a constant damping ratio locus is superimposed on the root loci then a value of gain for a constant value of damping can be obtained.

In Assignment 4 practicals were carried out on a process simulator with an exercise E4.3 asking how the response could be optimised for a given system gain. The following example shows how z-transforms can be used to set out the basic equations with fig A1.5. Set out in block diagram form is the system with Laplace transforms for each unit of the system.

As a Laplace transform the transfer function of the system will then be:

$$\frac{X_1(s)}{E(s)} = \frac{1-e^{-sT}}{s} \cdot \frac{A}{sT_1} \cdot \frac{1}{1+sT_2}$$

giving a corresponding z-transform of

$$\frac{X_1(z)}{E} = \frac{A_0(z-z_1)}{(z-1)(z-z_\beta)}$$

where $z_\beta = e^{-\beta}$ with $\beta = \frac{T}{T_2}$

with $z_1 = \frac{(1+\beta)e^{-\beta}-1}{(\beta-1)+e^{-\beta}}$ and

$$A_o = \frac{\beta - 1 + e^{-\beta}}{\beta} \cdot \frac{TA}{T_1}$$

Further Reading

For further details on gain, damping, etc. see "Automatic Control Systems" by B.C. Kuo p. 360 et. seq.

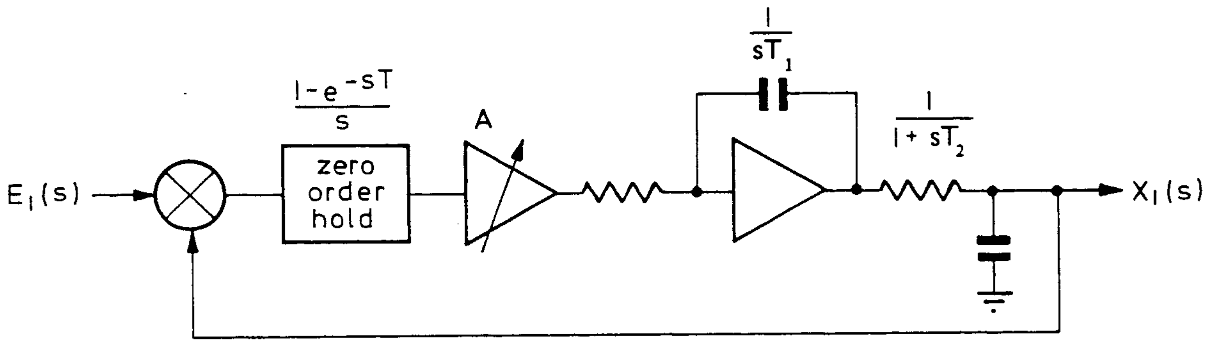


Fig A1.5

APPENDIX 2

The sampling Theorem

This states that:

> When a signal is sampled at a rate such that at least two samples are taken during the period of its highest-frequency component, the samples can be used to reconstruct the original signal.

Fig A2.1 shows a continually varying signal which is sampled to provide the values indicated by the blobs, at repeated intervals T, at a constant frequency $f_p = 1/T$.

To demonstrate the Sampling Theorem, we shall resort to a mathematical trick. Imagine that the signal is fed into a product modulator, or multiplier. If this modulator is to produce the same output as our sampler, the other input would

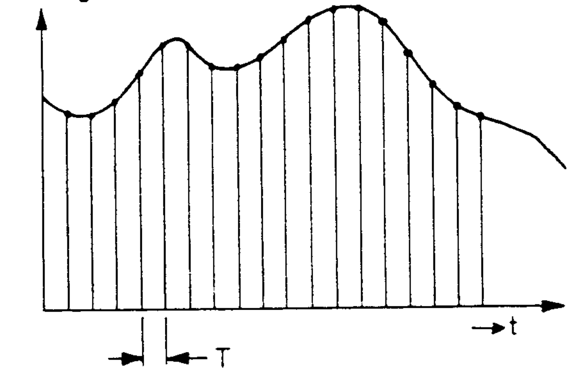


Fig A2.1

be a series of narrow pulses, as in fig A2.2. This pulse train can be analysed by Fourier's Theorem into a harmonic series. Call the waveform P, the pulse width dt (since it is supposed to be extremely narrow), and the pulse repetition frequency f_p. Then

$$P = f_p\,dt\,(1 + \cos 2\pi f_p t + \cos 2.2\pi f_p t + \cos 3.2\pi f_p t + \ldots)$$

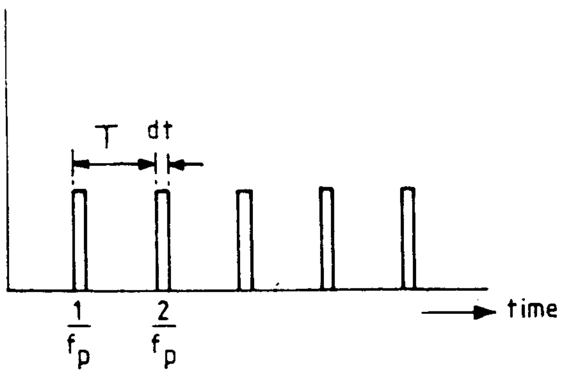


Fig A2.2

The factor $f_p dt$ is a dimensionless multiplier and a constant. Each of the terms in the bracket will give rise to a term in the output of the modulator, and clearly the first term is the one which will cause the original signal to be present in its output, unchanged except for the multiplier $f_p dt$. Incidentally, it is because dt is supposed to be small to the point of vanishing that we have to stretch the pulses using the hold unit.

Since we have shown that the original signal is present in the modulator output (irrespective of the value of f_p), why the restriction about taking at least two samples? To answer that we must look at the other terms in the series P.

Also, to simplify matters, let us take a simple signal

$$s = S \sin 2\pi f_s t.$$

With this signal, the second term in the series P will give rise to a component in the output $s f_p dt \sin 2\pi f_s t \cos 2\pi f_p t$, which may be expressed as

$$s\,f_p\,dt\,½[\sin 2\pi\,(f_s + f_p)\,t + \sin 2\pi\,(f_s - f_p)t].$$

We have, so to speak, a pair of sidebands either side of the component frequency f_p of the 'carrier' P.

Each of the harmonics (components of frequency nf_p) will likewise generate sidebands in the output signal.

These are most easily presented in a graphical form. For this we shall devise a notation, which will save us a lot of mathematical work. We are concerned with signals having frequency-components distributed over a frequency band. Fig A2.3 shows a conventional representation of the frequencies which may be present in the signal. On a horizontal frequency axis a triangle is erected, whose base indicates the extent of the frequency band, and which has its highest point at the highest frequency in the band, f_m.

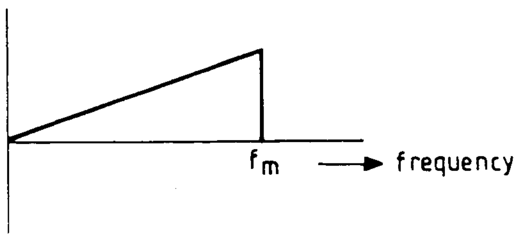


Fig A2.3

The lowest frequency in the sampling waveform (ignoring d.c) is the pulse repetition frequency f_p. This frequency and some typical signal frequency f_s after processing by the modulator produce product terms of frequencies $f_p \pm f_s$. Each harmonic of f_p will also be present in the sampling signal, i.e every frequency nf_p, where n in any integer. The harmonics and the signal will give rise to further frequencies $nf_p \pm f_s$. These frequencies are shown in fig A2.4 in the same notation as fig A2.3, with the convention that the high end of each triangle corresponds to the highest value, f_m, of f_s.

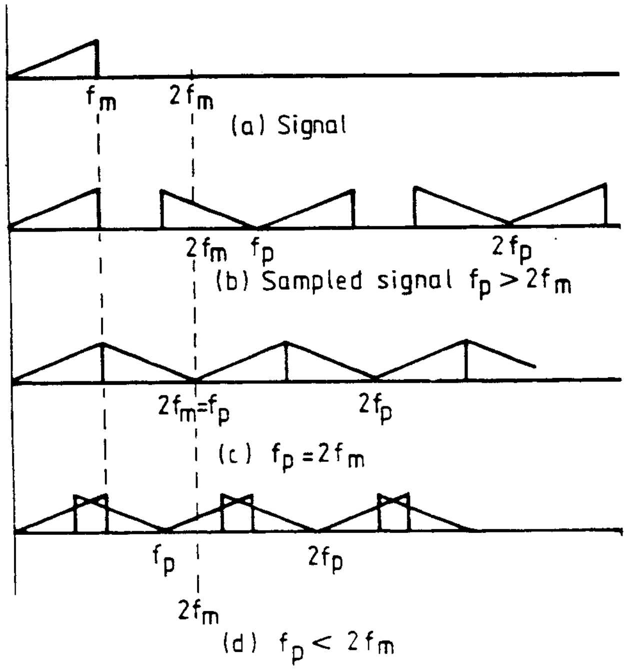


Fig A2.4

For each of the four conditions shown in fig A2.4 the left-most triangle represents the frequency components of the reconstruction of the original frequency. The other triangles represent further frequencies which must be eliminated (for otherwise they would corrupt the signal). The diagram shows that if $f_p > 2f_m$ (i.e the conditions required by the Sampling Theorem are met) then the unwanted frequencies are outside the wanted band of frequencies, and can therefore be removed by frequency-selective filters. If $f_p < 2f_m$ then some of the spurious frequencies lie within the wanted band and therefore cannot be separated. Such frequencies are called 'alias' frequencies.

The fact that the sample-and-hold unit stretches the samples out in time alters the relative magnitudes of frequency components, but does not in general alter which frequencies are present.

Circuit Description

In the module are a sample-and-hold circuit and a pulse generator which normally controls it. Fig M1 is a block diagram and fig M2 the full circuit diagram.

The input signal is fed by voltage follower AA to the sample-hold circuit AD, C2. When the analogue switch AD is 'on' the voltage on C2 follows the buffered input voltage. When the switch is off the voltage on C2 will remain substantially constant for as long as it is required, since neither the switch AD nor the output voltage follower will allow current which might alter C2's charge. In both conditions the output voltage follower AA provides a buffered output signal at low impedance.

If the sample-follow switch S5 is at 'follow' the 0V input to the switch holds it permanently 'on', so that the output always follows the input. When S5 is switched to sample, the analogue switch is controlled by a pulse generator which comprises an integrator AB and a comparator AC.

Positive feedback around the comparator makes it function as an analogue-driven switch with backlash. Driven by the integrator it generates pulses at a repetition frequency set by the 'frequency' potentiometer R1 and switch S1.

These controls together with R5, R6, R7 determine a charging current input to the integrator. On this depends the speed with which the output of AB goes negative. As it approaches a value of about −12V, comparator AC switches its output from approximately the positive supply potential to 0V. This causes the two analogue switches AD to conduct. One analogue switch places a new sample of the input on C2; the other (pins 9, 16) supplies a large negative current via R8 to the integrator input. This current causes the integrator to reset itself and the comparator AC, thus starting a new cycle.

Tr1 inverts the switching output of comparator AC to provide a buffered signal which goes positive during sampling pulses.

The pulse generator may be triggered by the analogue input signal or an external signal. This signal is compared by comparator AB with the potential set by 'level' control R10. The comparator produces trigger pulses (sharpened by positive feedback, R15) whose edges, passed via C3 to the comparator AC, force early termination of the 'hold' period.

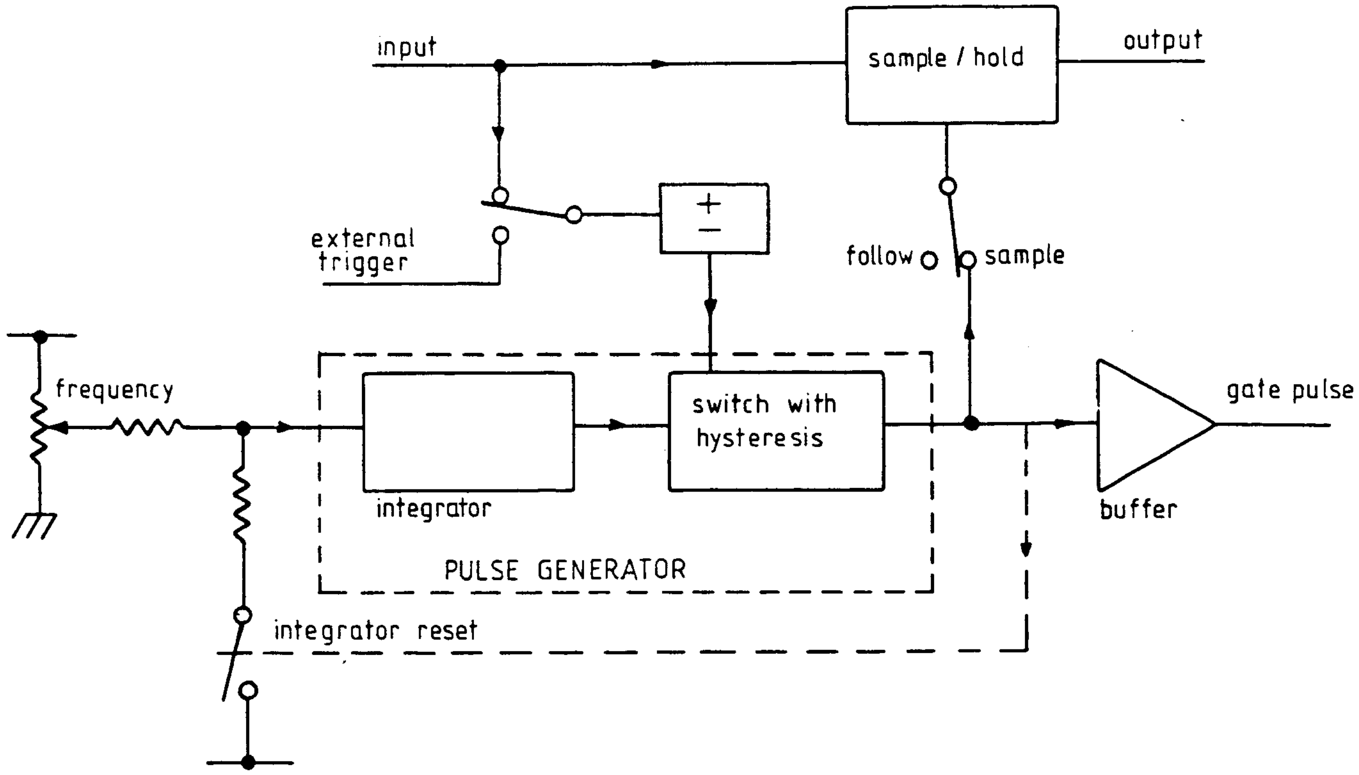


Fig M.1

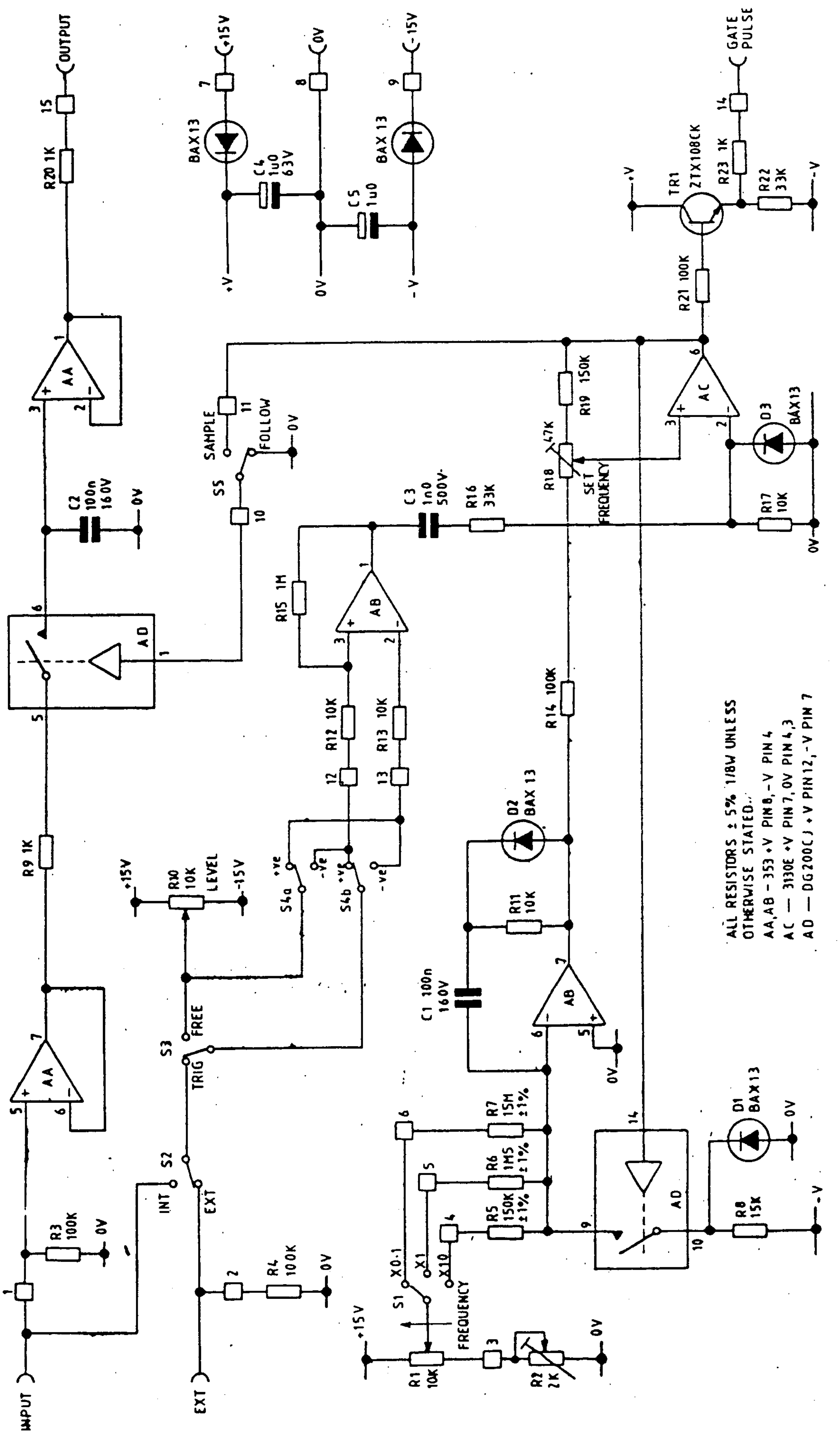


Fig M2 Sample and Hold unit SH150M – drg 3 – 150M – 9842, iss 3

Experimental Points

As the oscilloscope will be used with a function generator frequency output of 10Hz, care should be taken to see that the student is using the trigger and has steady traces.

The oscilloscope used in the experiment will need the following facilities:-

Dual trace
External trigger.

Assignment Exercises

E1.1 The student is asked if the output of the 150M followed the input when triangular sinusoidal and square waveforms were input.

The gain in each case was asked for and should be unity.

E1.2 Waveforms of the input and sampled output are drawn from the oscilloscope screen for the following values.

Input (volts)	Input (Hz) Sampling	Function
10	100	Triangular
10	100	Sinusoidal
10	100	Square
10	50	Triangular

Horizontal axes are placed on the waveforms and marked at quarter cycle intervals.

a) Comment on the effect of the sampling frequencies on the reproduction of the output is asked. It should be possible for the tracings to show that with a 10:1 ratio the reproduction is better than with a 5:1.

b) There should be no effective difference in the way that the three waveforms are sampled and the reproductions should be the same.

E1.3 With the controls set for sampling and triggering to occur at +135° on a triangular waveform input. The sampling frequency is also set at 6.5 on the x10 range.

The triggering point will then occur at 75% of the value of the input signal, as +180° will give the maximum value. It will occur in the middle of the sampling period as there will be 6.5 samples for each input waveform.

A tracing is to be taken of the oscilloscope screen to verify the point at which triggering occurs. Comparison is to be made with the effect varying the sampling frequency when the 150M is being triggered internally and externally.

E1.4 Read the notes on the Sampling Theorem contained in Appendix 2 and then suggest a type of filter that would reduce the guard space needed in the spectra at the expense of increased but tolerable delay. Show why the characteristics of such a filter would make it suitable and compare it with a simple RC lag filter.

Taking the case of a simple RC lag filter T1.1(a), a Bode diagram plot of its transfer function will be as in fig T1.1(b). If for example a filter such as a 2-pole Butterworth (maximally flat) type filter were used, the increased rate of cut-off enables a smaller guard space to be used.

Answers to Questions

Q1.1 The reason for using a trigger output on the function generator connected to the trigger input oscilloscope is to synchronise the beams to that of the waveform. At the low frequency of 10Hz unless the trace is very steady the sampling effect will not be shown clearly.

Q1.2 The first experiment is to obtain a follow output and the student should be

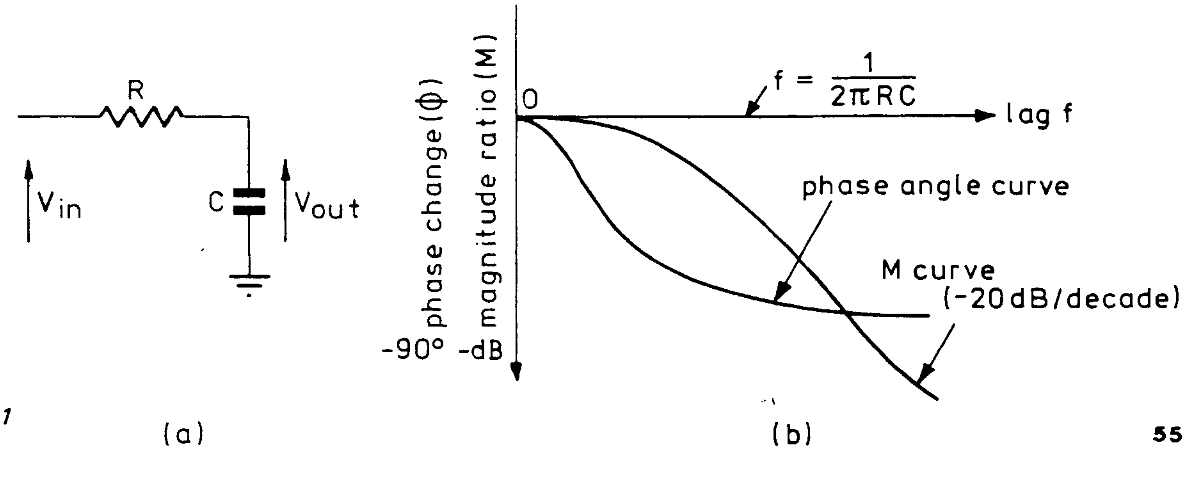


Fig T1.1

able to see an in-phase reproduction of a triangular 10Hz waveform.

Q1.3 The sampling period with the sampling frequency control set to 10 and the range switch to x10 is 10 milliseconds.

Q1.4 The advantage in having triggering facilities on a sample/hold unit is that the output can be synchronised to the input.

Q1.5 An explanation is required of the triggering controls on the 150M. The student should be able to appreciate that varying the level control will vary the level at which triggering takes place.

Q1.6 Varying the sampling frequency control will affect the point in a sample period. This is because the trigger will be set to operate at a certain point in the input cycle. The sampling frequency will then determine the exact number of sampling periods taking place in each cycle. The number of sampling periods will not be integers but will also include a fraction of a period that will vary if the sampling frequency is changed.

Q1.7 From the practicals that the student has carried out he should be able to say that sampling can be carried out at any frequency.

ASSIGNMENT 2

Experimental Points

The oscilloscope used in this assignment will need the following facilities.

External trigger
Frequency Sweep
Pulse brightness control input
Dual trace.

Assignment Exercises

E2.1 With a sinusoidal waveform input frequency of 1Hz and sampling frequency of 50Hz the output curves for the sampling period V_1 and V_5 in fig T2.1 are to be calculated and plotted. It is assumed that the value of V_1 is V volts and V_5 is 2.5 volts. There is a 33μF capacitor connector across the output to the -15V supply and the 150M has an output impedance of 1kΩ.

For V_1, the formula $v_1 = V_1\,(1-e^{-t/RC})$ volts where $V_1 = 2V$.
and v_5 the formula $v_5 = V_5\,e^{-t/RC}$ volts where V_5 is 2.5V, R = 1Ω, C = 33μF and t = .02 secs.

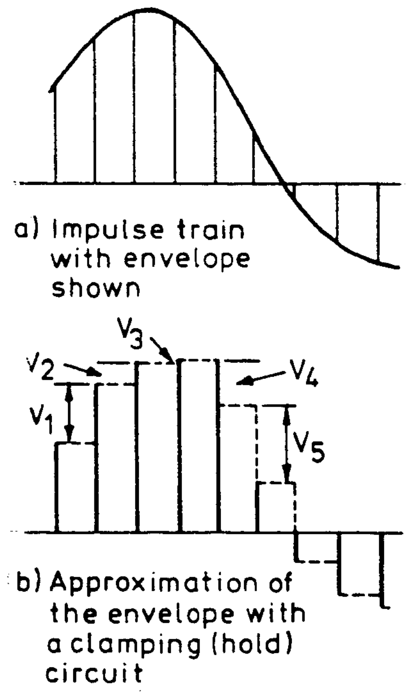


Fig T2.1

b) The student should notice that as he increased the sampling frequency that the output waveform using the 33μF as a filter increasingly took on the form of the input waveform. That the effects would in part (a) of this question increasingly smooth the steps as the sampling frequency was raised.

E2.2 A high sampling rate is needed to recover a square waveform when the filter is used. To see the reason for this we must first set out the equation for the square waveform.

$v = V\frac{\pi}{4}$ (sin ωt + 1/3 sin 3ωt + 1/5 sin 5ωt ....) where ωt is the instantaneous value and V the amplitude of the square waveform.

The reactance of the capacitance will now form a potential divider with the output of the 150M as in fig T2.2 the reactance of the fundamental will be much higher than on the harmonics. This means that the harmonics will be attenuated and the filtered output appears as in fig T2.3.

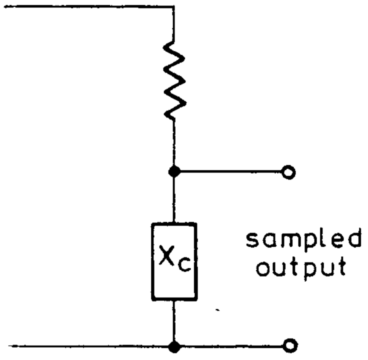


Fig T2.2

Unless the terms of the Sampling Theorem are met for the higher harmonics good reproduction cannot occur.

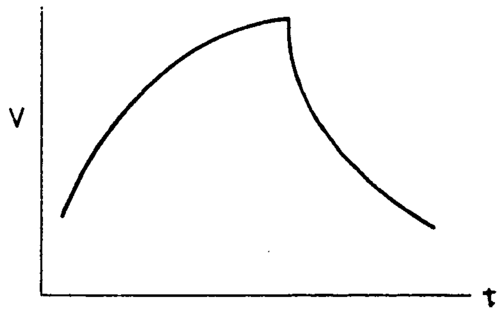


Fig T2.3

E2.3 Using a triangular output the student is to draw a diagram when the number of periods in each cycle is low. The voltage change in each step is large and the effect of the filter will then be to smooth these changes. This will give a near sinusoidal output.

With a much higher sampling frequency rate the step changes at the valleys and peaks of the waveform are small, the smoothing effect is then not able to distort the triangular form of the wave. If one compares the effect at 10Hz and at 100Hz, then for the time constant using a 33μF capacitor and the 1kΩ output impedance of the 150M, there will be a voltage of 95% of the step difference at 10Hz and only 26% at 100Hz.

E2.3 The student is to draw a block diagram of the essential parts of a sampling oscilloscope. A simplified diagram will look like fig T2.4.

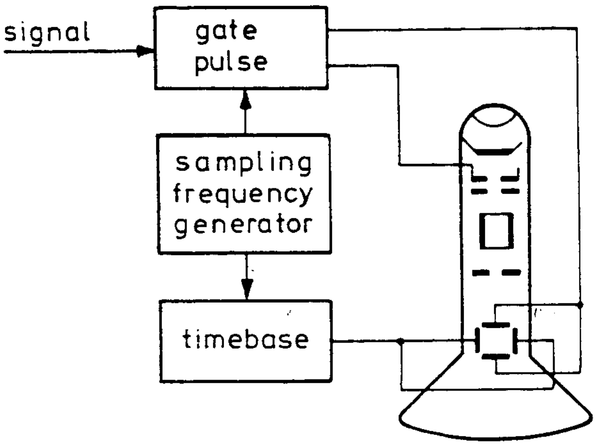


Fig T2.4

Answers to Questions

Q2.1 The purpose of sampling a signal is so that we can obtain instantaneous values at a rate that is a ratio between the signal and sampling frequency.

Q2.2 We hold the signal value during the sampling period, because the sampling only gives us its instantaneous value. If we need to operate on the sampled value then it is necessary to have a means of retaining, holding, its value.

Q2.3 If the sampling period is triggered at a set signal value, then we can obtain sampling that is synchronised to the output signal for display purposes.

Q2.4 When a capacitor is connected to the output of the 150M, in sampling mode, the capacitor will smooth the sampled values of the signal. The rate at which this is done will depend on the time constant of the circuit. The 150M has an output impedance of 1kΩ, so that this value with the capacitor capacitance will form the time constant. The effect will then be to smooth out the sampling steps in an exponential fashion.

Q2.5 The negative side of the capacitor is connected between the output of the 150M and the -15V supply and not 0V, because the input signal can be either positive or negative. The capacitor being electrolytic must be polarised correctly.

ASSIGNMENT 3

Experimental Points

It is important that the student understands the principles of operation of a Position Control Feedback Servomechanism of the type formed from the DC 150 Modular Servo kit. The first exercise requires an essay to be written explaining the kit layout.

Assignment Exercises

E3.1 An exercise is to be written explaining the operation of a Position Control Feedback system, as in fig T3.1. The essay is to include explanations on how the Operational Amplifier produces an error channel, the use of the Pre and Servo Amplifiers as well as to why feedback from the Output Rotary Pot produces proportional control and velocity control from the Tachogenerator and also the transient response of the system is to be dealt with and how overshoot occurs. It is suggested that the student reads Book 3 Part 1 of the Modular Servo Manual.

E3.2 A Function Generator is connected to the input of the Operational Amplifier and has a sinusoidal waveform of 2Hz and a 3-volt maximum amplitude. An explanation is to be given of why the indicator on the Output Pot will eventually rotate as the sampling rate of the Sample Hold circuit placed between the Operational Amplifier and the Pre-Amplifier is reduced from 100Hz to 0.5.

The error value is V_{in} - (V_{out} + V_{Tach}) at any instant. At a sampling frequency of 100Hz, there are fifty sampling periods in each sinusoidal half-cycles of the input signals. This will mean that the output of the Sample/Hold circuit will correspond very closely to the required error value and the output indicator will move, with a small delay, in unison with the input signal.

As the frequency is reduced there will no longer be sufficiently close correspondence of the Sample/Hold circuit to the required error value.

At a certain point the sampling frequency is low enough for the sampling output to be maintained for a sufficient time to cause the Output indicator to oscillate continuously about the alignment point. At the next sampling interval the error value may either drive the Output indicator once more in the same direction round the indicator or if the instantaneous error value turns out to have an opposite value, the direction of rotation will be in the opposite direction. The type of instability will then depend on the instantaneous error value at the sampling periods.

E3.3 The Function Generator is now switched to produce a square waveform output and the same question as in Exercise 3.2 is asked.

In Assignment 1 it was shown how a much higher rate of sampling is needed with a square waveform than with a sinusoidal waveform to produce a reasonably good reproduction of the input signal. This means that unless a high sampling rate is used with a square waveform input, the sampling of the error value will produce a square waveform in the output of the Sample/Hold circuit degraded to a series of steps causing overshooting of the Output indicator at the point of alignment. Further reduction of the sampling frequency will cause

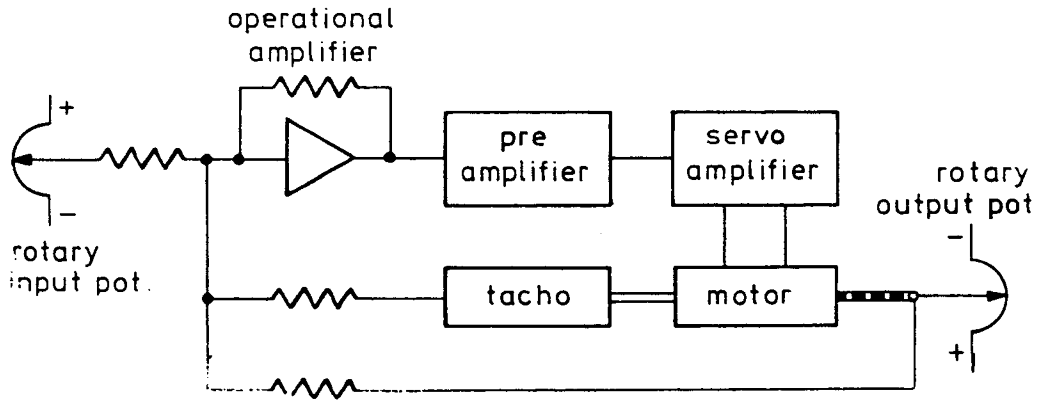


Fig T3.1

wild oscillation of the indicator and then uncontrolled rotation.

E3.4 A two servo system having a common error channel interposed between the Operational Amplifiers and the Pre-Amplifiers is to be drawn. If the servos have a simple lag type frequency response with bandwidths of 1Hz and 2Hz respectively, what sampling frequency would the student use?

An example of such a system is shown in fig T3.2. The feedback signals are compared with the driving signals to produce any error signals. Suitable switching then transmits the error signals along a common error channel where they are routed to each servo system. Through the use of hold circuits the error signals will be maintained at their values till subsequent signals are received.

A suitable sampling rate for the 1Hz servo would be 2.2Hz and for the 2Hz servo would be 4.4Hz, based on the Sampling Theorem. The sampling rate for the common error channel will then be 6.6Hz.

Answers to Questions

Q3.1 The Sample/Hold circuit is interposed in the error channel of fig T3.1 so that the channel maintains discrete signal values during each sampling period.

Q3.2 An input potentiometer connected to ±15V supplies, having a range of 300° has for an output of 3V a rotation of:-

$$\text{Rotation} = \frac{300^\circ}{30\text{V}} \times 3\text{V} = 30^\circ$$

Q3.3 With a 1Hz 3V square waveform input into the Operational Unit and a Sample/Hold set to FOLLOW the student should be able to get responses on the oscilloscope screen as in fig T3.3.

Q3.4 With the Sample/Hold circuit set to a sampling rate of 100Hz the waveforms should still appear as in fig T3.3.

Q3.5 There will be no change in the appearance of the waveforms because at a sampling rate of 100Hz the sampled output will virtually rebuild the shape of the required error signal.

Q3.6 The transient response is important as it shows the delay in time between an error output value and the motor running at a speed required by this error signal. So that if the motor is unable to respond fast enough to changes in error value, overshoot will occur. The degree to which the overshoots are damped gives an indication of the stability of the system. Although a gear system is used for the purpose of the assignment, backlash is ignored.

Q3.7 Reduction of the sampling rate will increase the sampling time intervals so that the consequent error changes may be too great, then as the output nears the point of alignment it will not come to a halt smoothly but will overshoot and oscillate about the point of alignment. Further reduction of the sampling intervals become too great in relation to approach speed of the output in relation to the point of alignment.

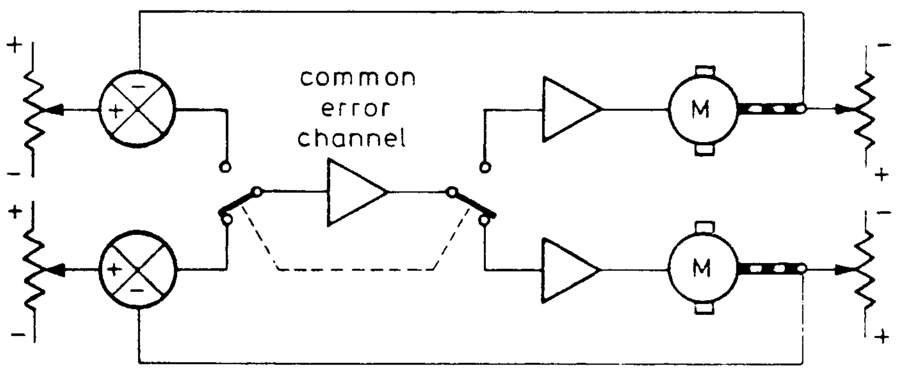


Fig T3.2

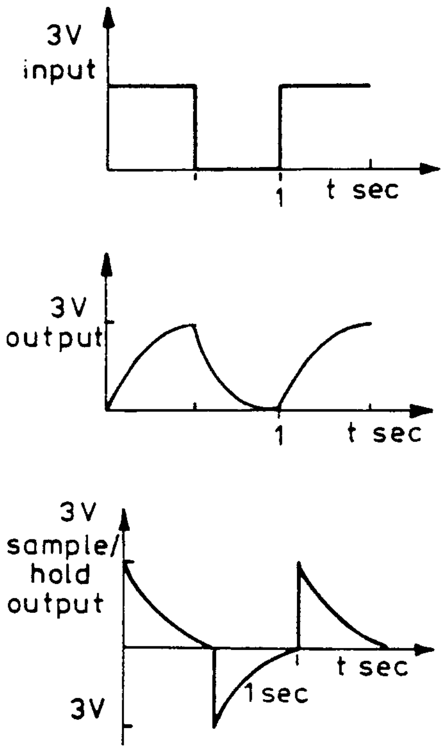

3V
input
1
t sec
3V
output
1
t sec
3V
sample/
hold
output
t sec
1sec
3V

Fig T3.3

ASSIGNMENT 4

Experimental Points

For the purpose of the assignment it is assumed that an MS150E Power Supply is available. If required an Application Note is available detailing how 0V and ±15V d.c supplies can be drawn from the power supply of the Process Control Simulator PCS327.

The last exercise in this assignment, E4.3 is only intended for advanced students who are practised in manipulating Z-transforms. Further reading on effects of gain and damping on the system transfer function can be found in Automatic Control Systems by B.C. Kuo (Prentice Hall).

Assignment Exercises

E4.1 On the basis of the observations made in Assignment 3, an explanation is to be given as to what would happen to the output if using an 0.03Hz square waveform input, the sampling frequency was gradually reduced from 10Hz to 0.3Hz. Also the effect of reducing the gain should be covered in the answer.

The system is using integral control so that the output signal will change at a rate proportional to the deviation. The amplitude of the output signal will also be proportional to the gain.

As the sampling rate is reduced, the length of time at which the output will be changing at a constant rate will increase. A point will come where the output will overshoot the alignment point during a sampling interval. The correcting deviation given during the next sampling interval will then cause an undershoot. The output will then oscillate about the steady state value governed by the sampling frequency and the number of oscillations and their amplitude will be decided by the system gain and the inertia of the system damping out the oscillations.

Reducing the gain will reduce the speed at which the output changes, in consequence during a sampling period there will have been a smaller change in deviation.

E4.2 This develops Exercise 4.1. What would be the effect of reducing the proportional band of 50% at a sampling frequency of 3Hz to 200% at 0.3Hz? Also what will be the frequency of the oscillatory signal superimposed on the steady state output?

The gain is reduced to a quarter at the lower sampling frequency. Although the period is ten times as great the change will be at a quarter of the speed. Therefore at the lower sampling frequency the output will have changed at 2.5 times the speed. The frequency of oscillation will be 3Hz and 0.3Hz respectively and the amplitude of oscillation at 0.3Hz will be greater as there will have been a greater output change in the sampling period.

E4.3 Fig T4.1 shows the transfer functions of items in the system used in this assignment, giving a loop gain of:

$$\frac{X_1(s)}{E(s)} = \frac{1 - e^{-sT}}{s} \times \frac{1}{sT_1} \times \frac{A}{1 + sT_2}$$

In terms of z-transforms

$$\frac{X_1(z)}{E(z)} = \frac{A(z_1 - z_2)}{(z-1)(z - z\beta)}$$

where $z_\beta = e^{-\beta}$ and $\beta = T/T_2$

As an exercise the response of the system is to be obtained from the above z- transform.

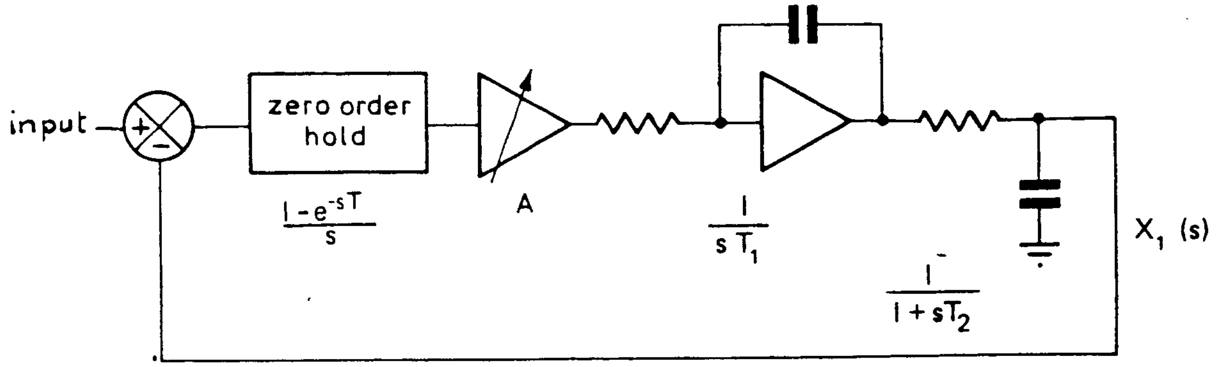


Fig T4.1

The gain of the amplifier A will then be

$$A = \frac{(\beta - 1 + e^{-\beta})}{\beta} \cdot \frac{TA}{T_1}$$

and

$$z_1 = \frac{(1 + \beta)e^{-\beta} - 1}{(\beta - 1) + e^{-\beta}}$$

This gives a pole-zero pattern of the generalised form as in fig T4.2.

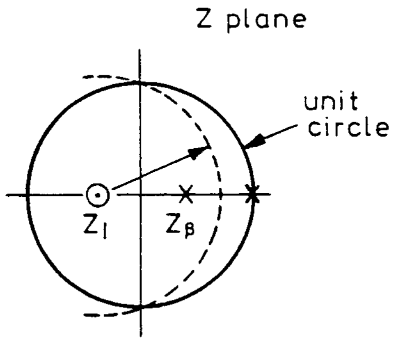


Fig T4.2

The 180° locus depends on the value of β.

For values of $\beta \leqslant 5$, the locus is within the unit circle as in fig T4.3.

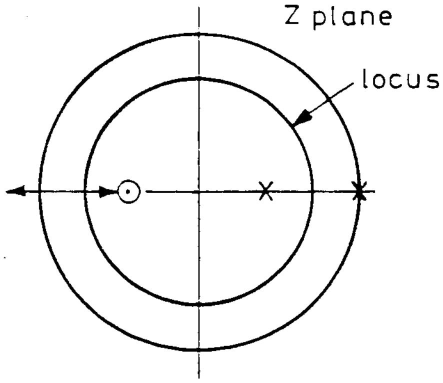


Fig T4.3

Regions outside the unit circle represent instability.

Answers to Questions

Q4.1 In complex process control plants there is a need for Sample/Hold circuits. This is because such systems will use a large number of valves, pumps and heating elements. There will be a complex interaction between the controllers and optimum operation of the whole system needs each element being referenced back to a central controller, at suitable intervals, so that calculations can be made as to the optimum setting for each controller. This will require a common error channel with Sample/Hold circuits connected to each controller.

Q4.2 From Q4.1, the advantage will be that as each Controller will be connected to the error channel for only a fraction of the time, the Sample/Hold circuit will maintain a driving signal during the time the error channel is connected to the other Controllers. During the time that the Controller receives a deviation signal, sampling will ensure that degradation of the signal does not take place.

Q4.3 The use and advantage of the Process Control Simulator PCS327 is that a simulation of many types of Controller can be made according to any combination of states and terms needed.

Q4.4 Integral control means that the output signal of the system will change at a rate proportional to the deviation.

Q4.5 The effect that integral control has on the performance of a Controller is that the steady state deviation of the system is reduced as there will be an output response as long as there is a deviation.

There is the disadvantage that the overall response time is reduced.

Q4.6 The front panel patching of the PCS327 includes a delay, see fig T4.4, to simulate the lapse of time that will occur in a Controller between a signal input and the actuator responding. An inverter is also patched to maintain the negative feedback sense around the loop.

Q4.7 In the first experiment the output waveform using the FOLLOW on the Sample/Hold, should be as in fig T4.5.

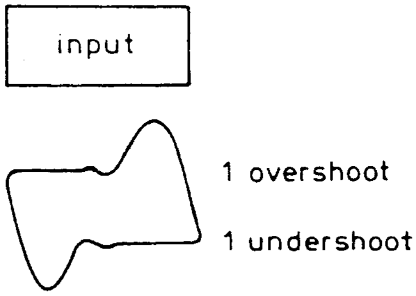


Fig T4.5

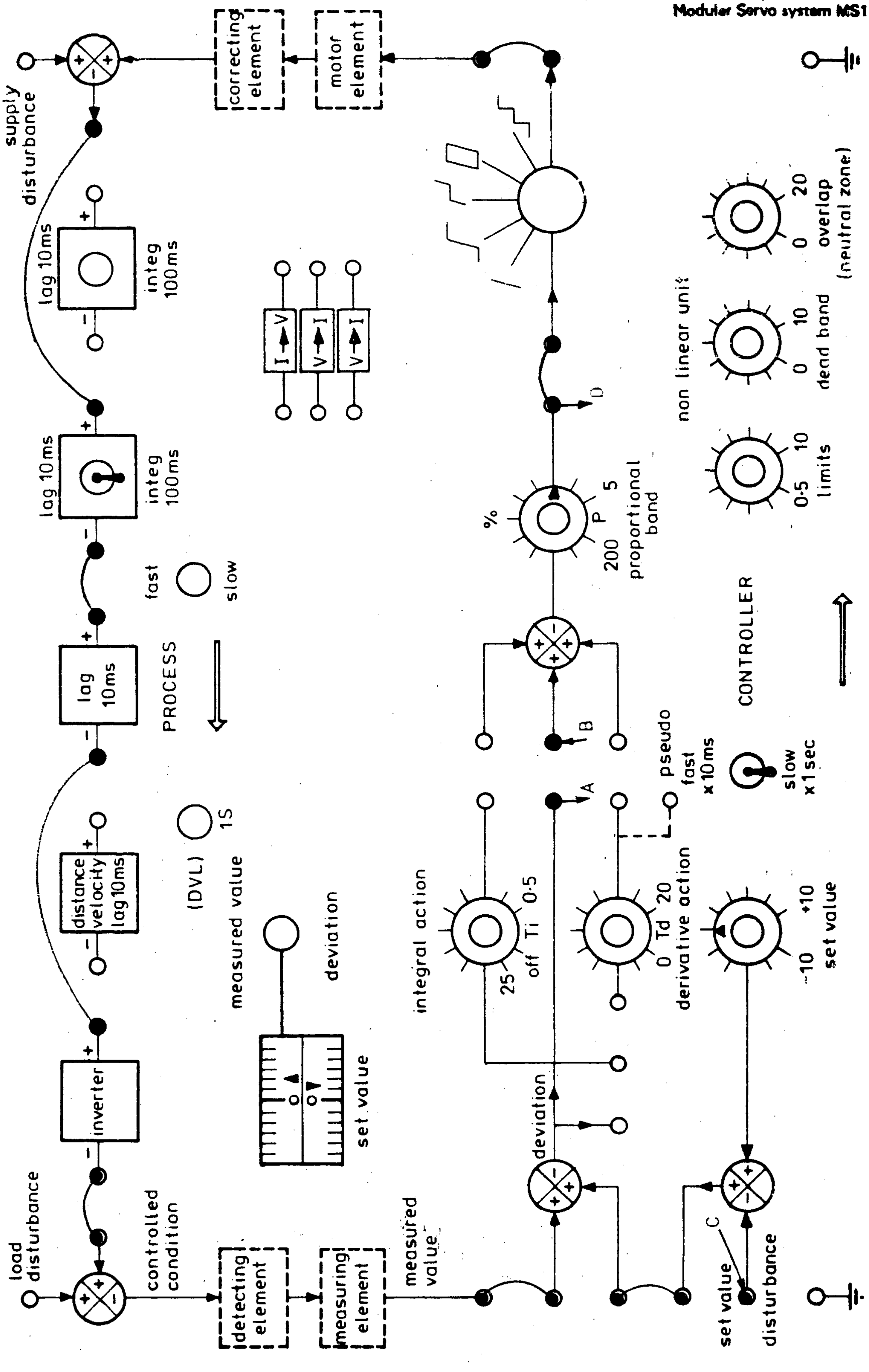


Fig T4.4 Front panel patching of the PCS327

Q4.9 The output waveform should stay the same because with an input signal of 0.03Hz the sampling frequency of 10Hz is relatively so large that each sampling interval is too small to cause any degradation in performance.

Q4.10 Reducing the sampling frequency to 1Hz will increase the number of overshoots and undershoots.

Q4.11 Altering the proportional band control from 50% to 200% will reduce the gain to a quarter.

ASSIGNMENT 5

Experimental Points

It is assumed that a Modular Servo Power Supply MS150E will be available, if this is not the case, an Application Note is available detailing the points in the Process Trainer PT326 from which ±15V and 0V d.c supplies can be obtained.

In these exercises the PROPORTIONAL BAND control on the PT326 is inoperative and the amplifier is set at unity gain. This is equivalent to a proportional band setting of 100%.

Assignment Exercises

E5.1a) Distance/velocity lag is the time interval between an alteration in the condition of a process and its detection by a transducer. Transfer lag is the time taken, following a step change in input, for the output to reach 63.2% of the final value. Five transfer lags can be taken as the effective time to reach the final value.

b) In a two-step control the output signal changes from a pre-set value to another value when the deviation changes sign. This means that the controlled deviation will alternate above and below a mean value at a frequency that is determined by a combination of the two lag effects and the energy level at which the correcting element operates.

With continuous control the correcting element will operate at a value determined by the value of the deviation.

c) With continuous control, if there is a disturbance at the input, causing a step change in the controlled condition the response of the system will be determined by a combination of the effect of transfer lag and the energy level of the correcting level. If the system is underdamped then as in fig T5.1 there will be a series of undershoots and overshoots depending on the effectiveness of the damping.

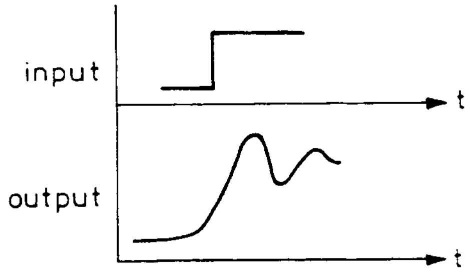


Fig T5.1

E5.2 With a block diagram layout as in fig T5.2 a 5V peak-to-peak 1.0 Hz square waveform disturbance and with Sample/Hold set to FOLLOW the output waveform will appear as in fig T5.3 showing that the system is slightly underdamped.

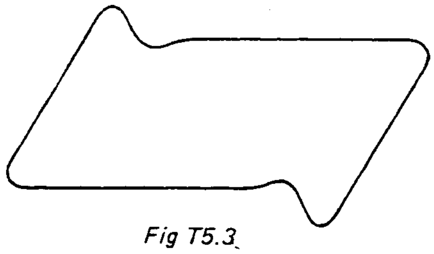


Fig T5.3

E5.3 With the Sample/Hold now set to SAMPLE there should still be the same output response as in fig T5.3. This is because the ratio of sampling to input frequency is so great, 10:1, that there is virtually no difference between the Sample and Follow modes. The sampling period being far too small to cause any noticeable effect on the fidelity of the deviation to the required changes.

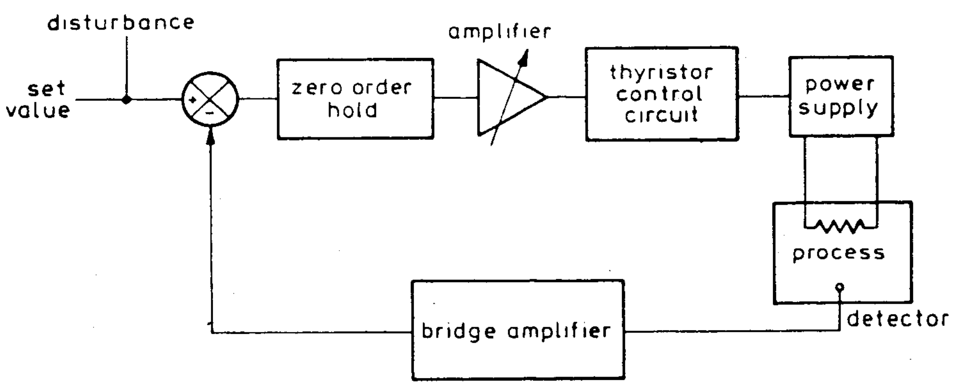


Fig T5.2

E5.4 The degree of oscillation about the mean value of the output response when the Sample/Hold is set to SAMPLE, is governed by the transfer lag of the heater, the sampling frequency and the gain. As the sampling period is increased, so the deviation at any sampling instant will be held at that value for the sampling period. The thyristor control circuit will then power the heater at a value proportional to $K\theta$ (where K = system gain and θ = deviation). If the output is greater than the input value at the end of the sampling period, then the deviation will have changed sign and so the heater will be switched off. However the transfer lag of the heater will have made the heater gain energy that it will radiate during its switched off time. If at the end of the next sampling period all this heat has not been radiated, then the effect of the system gaining more energy than it loses on alternate sampling periods will cause the output response to become unstable. The frequency of oscillation will then correspond to the sampling frequency.

E5.5 The system performance will become satisfactory with a sampling frequency of about 3Hz.

From E5.4 it will be seen that due to the transfer lag, there will be an initial overshoot at alignment. The damping of the system will then be sufficient to produce a steady state after the next undershoot.

Questions Raised

Q5.1 The sampling principles and techniques that can be demonstrated by making a hybrid experiment using the Process Trainer PT326 and Sample/Hold SH150M are the application of sampling to a common error channel. The hot air process produced in the PT326 is representative of the many continuous processes occurring in industry, such as in a chemical reactor, refinery, furnaces, etc. In any complex Process Control system there will be a variety of variables needing control in the Process together with the control of the settings of a large number of Controls in the rest of the system. A centralised controller using feedback information as to the actual state of the various elements can act as a basis for sending deviation signals along a common error channel. This ensures that the system will operate under optimum conditions. Taking the PT326 as being part of such a system the signal amplitude controlling the heater Power Supply must be sampled so that it will not degrade the system response during its time sharing period.
During the rest of the time the deviation must be held till the next time share period.

On the PT326 there is no access for the Sample/Hold between the Comparator and Proportional Band. However as the sampling circuit has unit gain it can, without affecting the system performance, be placed between the Proportional Band and the Continuous Control.

Q5.2 A satisfactory output response for the Process Trainer is shown in fig T5.3.

Q5.3 With the Sample/Hold set to Sample the output response of the Process Trainer could tolerate one overshoot and one undershoot.