ANI653 DIGITAL CONTROL ENGINEERING

1) What are the time domain specifications needed to design a control system?

The time domain specifications needed to design a control system are

1. Rise time
2. Peak overshoot
3. Settling time
4. Damping ratio
5. Natural frequency of oscillation

2) Write the necessary frequency domain specifications for design of a control system?

The frequency domain specifications required to design a control system are

1. Phase margin
2. Gain margin
3. Resonant peak
4. Bandwidth

3) What are the two methods of designing a control system?

The two methods of designing a control system are design using root locus and design using bode plot.

In design using root locus, the system is designed to satisfy the specified time domain specifications. In design using bode plot, the system is designed to satisfy the specified frequency specifications.

4) What is the compensation?

The compensation is the design procedure in which the system behaviour is altered to meet the desired specifications, by introducing the additional device called compensator.

5) What is the compensator? What are the different types of compensator?

A device inserted to the system from the purpose of satisfying the specifications is called compensator.

The different types of compensators are lag compensator, lead compensator and lag-lead compensator.

6) What are the two types of compensation schemes?

The two types of compensator schemes employed in control system are series compensation and feedback or parallel compensation.

7) What is series compensation?

The series compensation is a design procedure in which the compensator is introduced in series with plant to alter the system behaviour and to provide satisfactory performance.

The block diagram of series compensation scheme is shown in fig

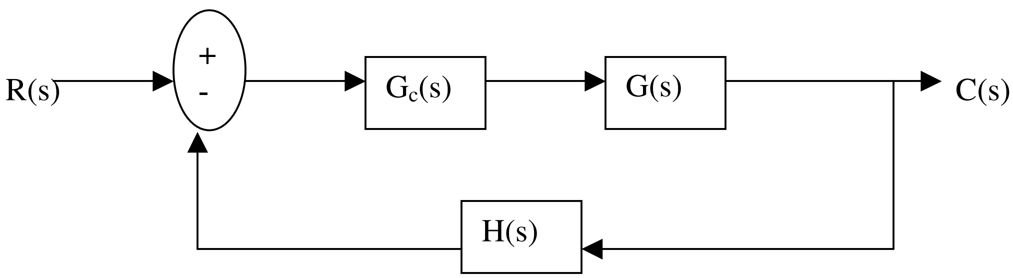


Fig: Series compensation

$G_c(s)$ = transfer function of series compensator

G(s) = open loop transfer function of the plant.

H(s) = feedback path transfer function.

8) What is feedback compensation?

The feedback compensation is a design procedure in which the compensator is introduced in the feedback path so as to meet the desired specification. It is also called parallel compensation.

The block diagram of feedback compensation scheme is shown in figure

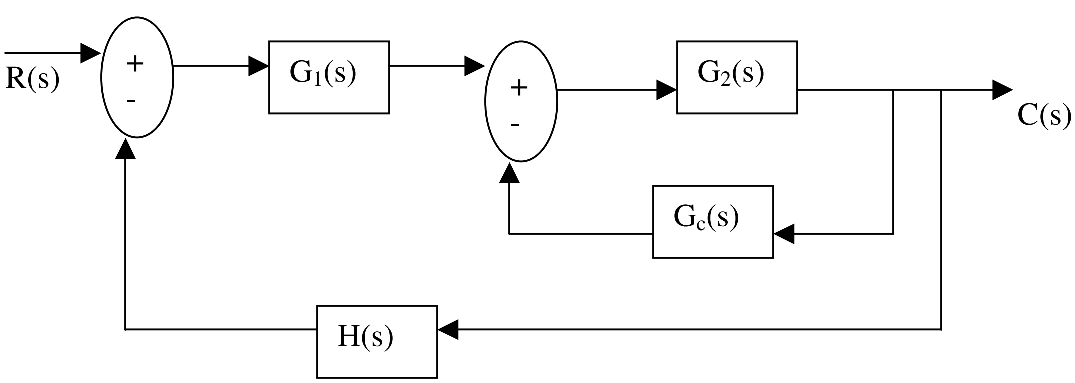


Fig: feedback compensation

$G_c(s)$ = transfer function of feedback compensator

$G_1(s)$, $G_2(s)$ = open loop transfer function of the component of the plant.

H(s) = feedback path transfer function.

9) What is lag compensation?

The lag compensation is the design procedure in which the lag compensator is introduced in the system so as to meet the desired specifications.

10) What is the lag compensator? Give an example.

A compensator having the characteristics of a lag network is called lag compensator. If a sinusoidal signal is applied to a lag compensator, then in steady state the output will have a phase lag with respect to input.

An electric lag compensator can be realized by a R-C network. The R-C network shown in fig is an example of lag compensator.

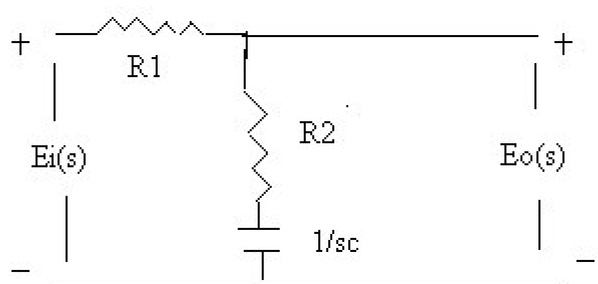


Fig: lag compensator

11) What is the transfer function of lag compensator and draw its pole-zero plot?

Transfer function of Gc(s) =

$$\frac{S+1/T}{S+1/\beta T}$$

lag compensator

the lag compensator has a pole at s = -1/ßT and a zero at s = -1/T. Since ß>1 and T>0, the pole of lag compensator is nearer to origin. The pole-zero plot of lag compensator is shown in fig

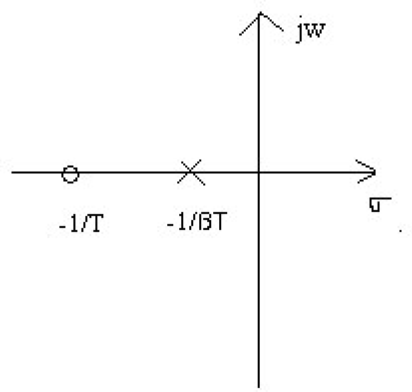


Fig: pole-zero plot of lag compensator

12) What are the characteristic of lag compensation? When the lag compensation is employed?

The lag compensation improved the steady state performance; reduce the bandwidth and increasing the rise time. If the pole introduced by the compensator is not cancelled by a zero in the system and then the lag compensator increases the order of the system by one.

When a system is stable and does not satisfies the performance specifications then lag compensation can be employed so that the system is redesigned to satisfy the performance specifications.

13) When maximum phase lag occurs in lag compensator? Give the expression for maximum lag angle and the corresponding frequency.

The maximum phase lag occurs at the geometric mean of two corner frequencies of the lag compensator.

Maximum lag phase angle, $\text{Ø}_m = \tan^{-1}(1-\beta)/2\sqrt{\beta}$

Frequency corresponding to Ø_m , $w_m = \sqrt{w_{c1} w_{c2}} = \sqrt{1/T \; 1/\beta T} = 1/(T\sqrt{\beta})$

14) What is lead compensation?

The lead compensation is a design procedure in which a lead compensator is introduce in the system so as to meet the desired specifications.

15) What is lead compensator? Given an example.

A compensator having the characteristics of a lead network is called lead compensator. If a sinusoidal signal is applied to a lead compensator, then in steady state the output will have a phase lead with respect to input.

An electric lead compensator can be realized by a R-C network. The R-C network shown in fig is an example of lead compensator.

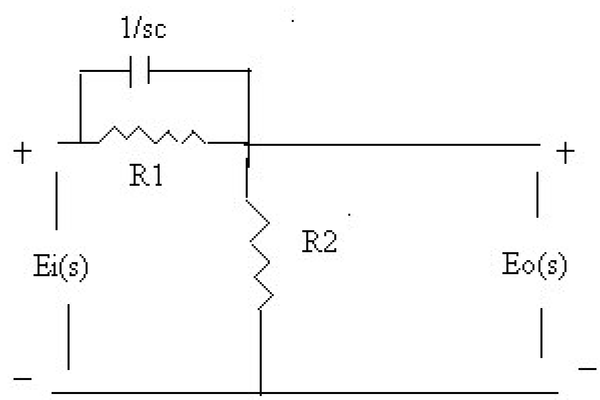


Fig: Electric lead compensator

16) What is the transfer function of lead compensator and draw its pole-zero plot?

Transfer function of Gc(s) =

$$\frac{S+1/T}{S+1/T\,[illegible]}$$

lag compensator

the lag compensator has a pole at s = - $1/T$[illegible] and a zero at s = -1/T. Since [illegible] >1 and T>0, the pole of lag compensator is nearer to origin. The pole-zero plot of lag compensator is shown in fig

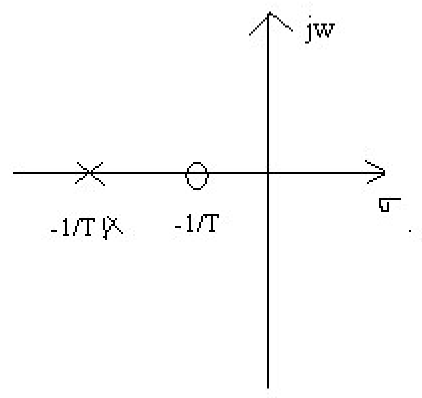


Fig: pole-zero plot of lead compensator

17) What are the characteristic of lead compensation? When the lead compensation is employed?

The lead compensation increasing the bandwidth and improved the speed of performance. It also reduces peak overshoot. If the pole introduced by the compensator is not cancelled by a zero in the system and then the lead compensator increases the order of the system by one.

18) When maximum phase lead occurs in lead compensator? Give the expression for maximum lead angle and the corresponding frequency.

The maximum phase lead occurs at the geometric mean of two corner frequencies of the lead compensator.

Maximum lead phase angle, $\O m = \tan^{-1}(1-ß)/2\sqrt{ß}$

Frequency corresponding to $\O m$, $wm = \sqrt{wc1wc2} = \sqrt{1/T \; 1/ßT} = 1/T\sqrt{ß}$

19) What is lag-lead compensation?

The lag-lead compensation is a design procedure in which a lag compensator is introduce in the system so as to meet the desired specifications.

20) What is lag-lead compensator? Given an example.

A compensator having the characteristics of a lag-lead network is called lag-lead compensator. If a sinusoidal signal is applied to a lag-lead compensator, then in steady state the output will have a phase lag and lead with respect to input but in different frequency region.

An electric lag-lead compensator can be realized by a R-C network. The R-C network shown in fig is an example of lag-lead compensator.

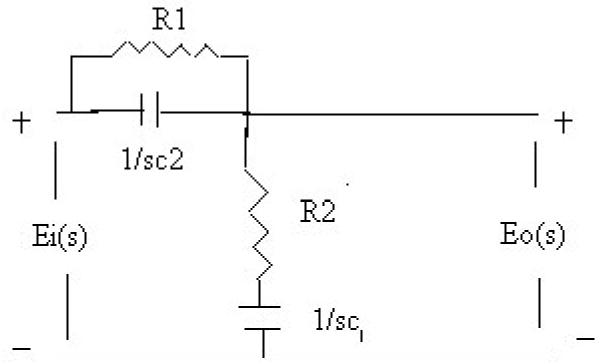


Fig: Electric lag-lead compensator

21) What is the transfer function of lag compensator and draw its pole-zero plot?

Transfer function of Gc(s) =

$$\frac{S+1/T}{S+1/\beta T} \cdot \frac{S+1/T}{S+1/T\beta}$$

lag compensator

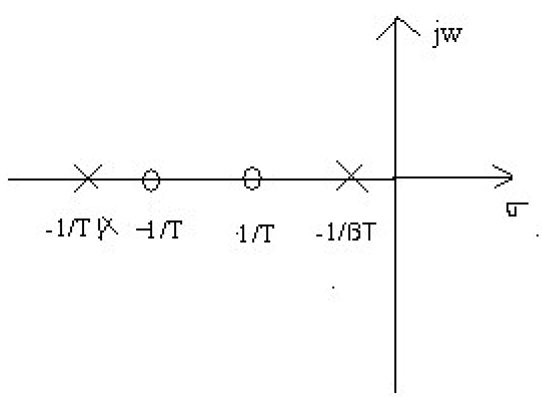


Fig: pole-zero plot of lag-lead compensator

22) What are the characteristic of lag-lead compensation? When the lag-lead compensation is employed?

The lag-lead compensation has the characteristic of both lag lead compensation. The lag compensation improved the steady state performance and decreases the bandwidth. The lead compensation increases the bandwidth and improved the speed of performance. It also reduces peak overshoot.

If the pole introduced by the compensator is not cancelled by a zero in the system and then the lag-lead compensator increases the order of the system by two.

23) What is the P-controller and what are its characteristics?

The proportional controller is a device that produces an output signal which is proportional to the input signal.

The proportional controller improves the steady state tracking accuracy, disturbance signal rejection and relative stability. It also decreases the sensitivity of the system to parameter variation.

24) What is the PI-controller and what are its effect on system performance?

The PI-controller is a device that produces the output signal consisting of two terms-one proportional to the input signal and the other proportional to the integral to the input signal.

The introduction of PI-controller in the system reduces the steady state error and increases the order and type number of the system by one.

25) What is the transfer function of PI-controller?

Transfer function of PI-controller $G_c(s) = K_p + K_i/s = K_p(s+K_i/K_p)/s$

26) What is the PD-controller and what are its effect on system performance?

The PD-controller is a device that produces the output signal consisting of two terms-one proportional to the input signal and the other proportional to the derivative to the input signal.

The PD-controller increasing the damping of the system which results in reducing the peak overshoot.

27) What is the transfer function of PD-controller?

Transfer function of PD-controller Gc(s) = Kp+ Kds = Kd(s+Kp/Kd)

28) What is the PID controller and what are its effect on system performance?

The PID controller is a device that produces the output signal consisting of three terms-one proportional to the input signal another one proportional to the integral to the input signal and the third one proportional to the derivative to the input signal.

The PID controller stabilizes the gain, reduces the steady state error and the peak overshoot.

29) What is the transfer function of PID-controller?

Transfer function of PID-controller Gc(s) = Kp+ Ki/s + Kds = (Kds2+Kps +Ki)/s

30) What is the feedback compensator?

The feedback compensation is a design procedure in which the compensator is placed in an internal feedback path around one or more components of the forward path so as to meet the desired specifications.

31) Draw the block diagram of a feedback compensator scheme?

The block diagram of the popular feedback scheme employed in two the control system is shown in fig

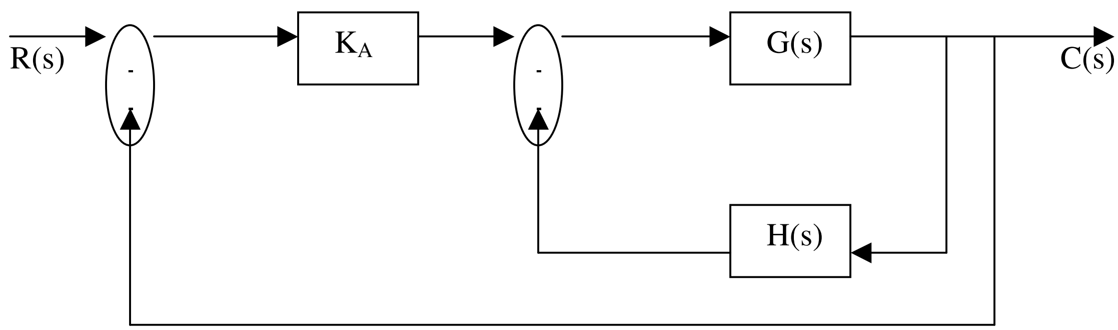


Fig: Feedback compensator scheme

Here, H(s) = transfer function of feedback compensator

K_A = A parameter to adjust the velocity error constant of the system

32) What is the disadvantage in rate feedback and how it is eliminated?

The disadvantage in rate feedback is that the system velocity error constant K_V is reduced. This undesirable effect can be eliminated by reducing the feedback signal in the low frequencies by introducing a high pass filter in cascade with rate device as shown in fig

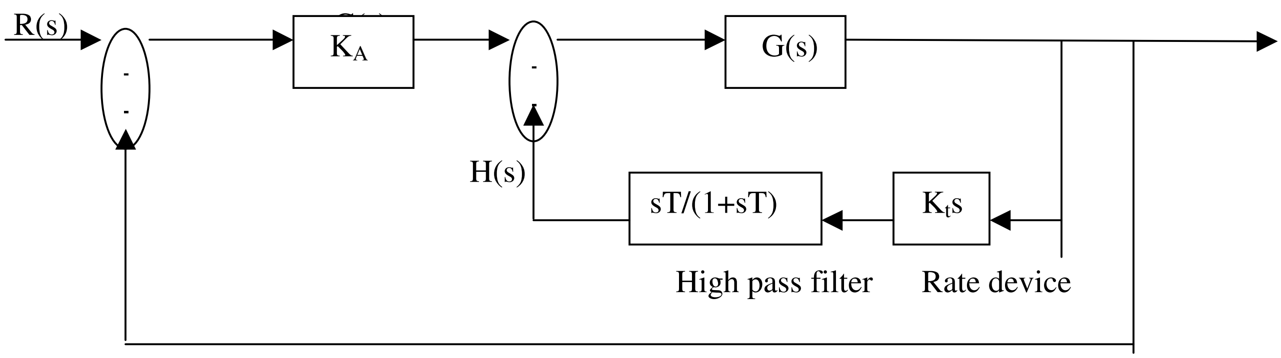


Fig: Feedback compensator with high pass filter in cascade with rate device

33. What is sampled data control system?

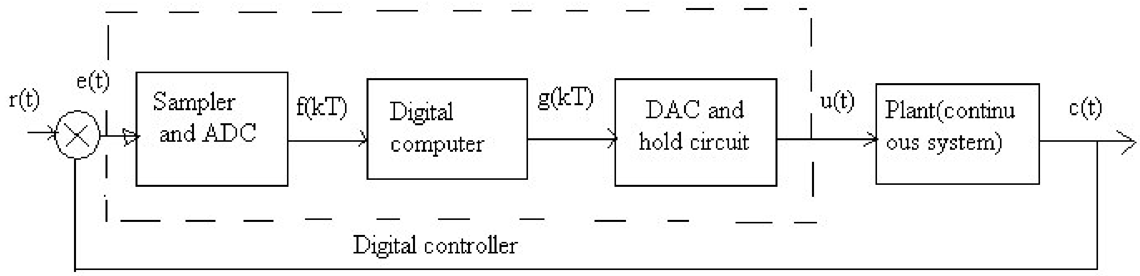
When the signal or information at any or some points in a system is in the form of discrete pulses, then the system is called discrete data system or sampled data system.

34. When is the control system called?

The control system becomes a sampled data system in any one of the following situations.

- When a digital computer or microprocessor is employed as a part of the control loop.
- When the control components are used on time sharing basis.
- When the control signals are transmitted by pulse modulation.
- When the output or input of a component in the system is digital or discrete signal.

35. Draw the block diagram of a sampled data control system?



e(t) – error signal(analog)
f(kT) – Digital error signal
u(t) – Control signal (analog),
g(kT) - Digital control signal.

36. Distinguish between discrete time systems and continuous time systems.

Discrete time systems	Continuous time systems
I. Devices or algorithms that can process discrete-time signals.	Devices that process analog signals.
II. The input and output signals are digital or discrete.	The input or output variables are analog or continuous time signals.

37. Write the advantages and disadvantages of sampled data control system.

Advantages:

i. Systems are highly accurate, fast and flexible.

ii. Use of time sharing concept of digital computer results in economical cost and space.

iii. Digital transducers used in the system have better resolution.

iv. The digital components are less affected by noise,non-linearities and transmission errors of noisy channel.

Disadvantages:

i. Conversion of analog signals to discrete-time signals and reconstruction introduce noise and errors in the signal.

ii. Additional filters have to be introduced in the system if the component of the system does not have adequate filtering characteristics.

38. What is a digital controller?

A digital controller is a device introduced in the control system to modify the error signal for better control action. The digital controller can be a special purpose computer or a general –purpose computer or it is constructed using non-programmable digital devices.

39. Compare the analog and digital controller.

Analog controller	Digital controller
1. Complex	Simple
2. Costlier than digital controller.	Less costly than analog controller.
3. Slow acting	Fast acting.
4. Non-programmable.	Programmable.
5. Separate controller should be employed for each signal.	A single controller can be used to control more than one signal on time shared basis.

40. What are the advantages of digital controllers?

1. The digital controllers can perform large and complex computation with any desired degree of accuracy.
2. The digital controllers are easily programmable and are hence versatile.
3. Digital controllers have better resolution.

41. Explain the terms sampling and sampler.

- Sampling is a process in which the continuous-time signal is converted into a discrete-time signal by taking samples of the continuous-time signal at discrete time instants.
- Sampler is a device which performs the process of sampling.

42. What is periodic sampling?

The periodic sampling is a sampling process in which the discrete-time signal or sequence is obtained by taking samples of continuous-time signal periodically or uniformly at intervals of T seconds. Here T is called 'sampling period' and $1/T=F_s$ is called 'sampling frequency'.

43. State (Shannon's) sampling theorem.

Sampling theorem states that a band limited continuous-time signal with highest frequency f_m hertz can be uniquely recovered from its samples provided that the sampling rate F_s is greater than or equal to $2f_m$ samples per second.

44. What is meant by quantization?

The process of converting a discrete-time continuous valued signal into a discrete-time discrete valued signal is called quantization. In quantization the value of each signal sample is represented by a value selected from a finite set of possible values called quantization levels.

45. What is coding?

The coding is the process of representing each discrete value by an n-bit binary sequence (or code or number).

46. What are hold circuits?

Hold circuits are devices used to convert discrete time signals to continuous time signals.

47. What is zero-order hold?

The zero-order hold is a hold circuit in which the signal is reconstructed such that the value of reconstructed signal for a sampling period is same as the value of last received sample.

48. What is first-order hold?

The first-order hold is a hold circuit in which the last two signal samples (current and previous sample) are used to reconstruct the signal for the current sampling period. The reconstructed signal will be a straight line in a sampling period, whose slope is determined by the current and previous sample.

49. Define acquisition time.

- In analog-to-digital conversion process, the acquisition time is defined as the total time required for obtaining a signal sample and the time for quantizing and coding.
- It is also called conversion time.

50. Define settling time.

In digital-to-analog conversion process, the settling time is defined as the time required for the output of the DAC to reach and remain within a given fraction of the final value, after application of input code word.

51. What is "Hold mode droop"?

The changes in signal voltage level in the hold circuits during hold mode or hold period is called hold mode droop.

52. What are the problems encountered in a practical hold circuit?

The problems encountered in a practical hold circuit are

1. Errors in the periodicity of sampling process.
2. Non-linear variations in the duration of sampling aperture.
3. Droop in the voltage held during conversion.

53. How are the high frequency noise signals in the reconstructed signal eliminated?

The high frequency noise signals introduced by hold circuits in the reconstructed signal are easily filtered out by the various elements of the control system, because, the control system is basically a low pass filter.

54. Define one-sided and two-sided z-transform.

The z-transform (two-sided z-transform) of a discrete sequence, f(k) is defined as the power series,

$$F(z) = Z\{f(k)\} = \sum_{k=-\infty}^{\infty} f(k)z^{-k}$$

where z is a complex variable.

The notation z{f(k)} is used to denote z-transform of f(k).

The one-sided z-transform of f(k) is defined as the power series,

$$F(z) = Z\{f(k)\} = \sum_{k=0}^{\infty} f(k)z^{-k}$$

where z is a complex variable.

55. What is region of convergence (ROC)?

- The z-transform of a discrete sequence is an infinite power series, hence the z-transform exists only for those values of z for which the series converges.
- If F (z) is z-transform of f (k) then the ROC of F (z) is the set of all values of z, for which F (z) attains a finite value.

Note:

- The infinite geometric series sum formula is

$$\sum_{k=0}^{\infty} C^k = 1/ 1\text{-}C;\ \text{where } |C|$$

- The finite geometric series sum formula is

$$\sum_{k=0}^{M-1} C^k = C^M\text{-}1/C\text{-}1;\ \text{when } C \neq 1$$

$$= M \qquad ;\ \text{when } C = 1$$

56. State the initial value theorem and final value theorem with regard to z-transform.

Initial value theorem:

If f (k) is causal and stable and F (z) exists with z =1 included in the ROC, then the initial value theorem is given by,

$$f(0) = \underset{z \to \infty}{Lt} F(z) \quad ;\text{where } F(z) = Z\{f(k)\}$$

Final value theorem:

If f(k) is causal and stable and F(z) exists with z =1 included in the ROC, then the final value theorem is given by,

$$f(\infty) = = \lim_{z \to 1} (1-z^{-1}) F(z) \quad ; \text{where } F(z) = Z\{f(k)\}$$

57. Find the z-transform of i) Unit step signal. ii) a^k iii)e^{-akT}

i) Unit step signal

The unit step signal, u (k) = 1 for k>=0
The z-transform of u (k) = Z {u (k)}

$$= \sum_{k=0}^{\infty} z^{-k}$$

$$= z/ (z-1)$$

ii) a^k

$$Z\{a^k\} = \sum_{k=0}^{\infty} a^k z^{-k}$$

$$= \sum_{k=0}^{\infty} (a z^{-1})^k$$

$$= 1/ (1-az^{-1})$$

$$= z/ (z-a)$$

iii) e^{-akt}

$$Z\{e^{-aKt}\} = \sum_{k=0}^{\infty} e^{-akT} z^{-k}$$

$$= \sum_{k=0}^{\infty} (e^{-aT} z^{-1})^k$$

$$= 1/ (1-e^{-aT}z^{-1})$$

$$= z/ (z-e^{-aT})$$

58. What are the different methods available for inverse z-transform?

1. Direct evaluation by contour integration (or) complex inversion integral.
2. Partial fraction expansion.
3. Power series expansion.

59. What is linear discrete-time system?

- A discrete time system is a device or algorithm that operates on a discrete-time signal called the input or excitation, according to some well-defined rule, to produce another discrete-time signal called the output or the response of the system.
- A discrete time system is linear if it obeys the principle of superposition and it is time invariant if its input-output relationship does not change with time.

60. How is the output of an LDS related to impulse response?

The output or response of an LDS is given by convolution of the input r(k) with the impulse response h(k) of the system. It is expressed as,

$$C\ (k) = r\ (k) * h\ (k)$$

61. What is the equivalent representation of pulse sampler with ZOH?

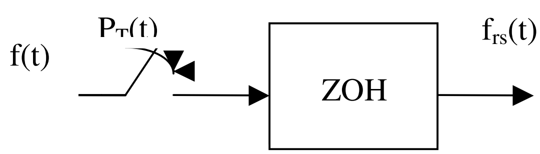


Fig.1.Pulse sampler with ZOH

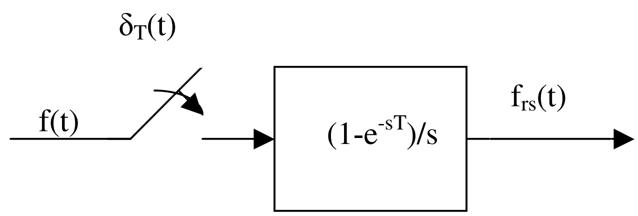


Fig.2.Equivalent representation of pulse sampler with ZOH

62. Sketch the frequency response curve of ZOH device.

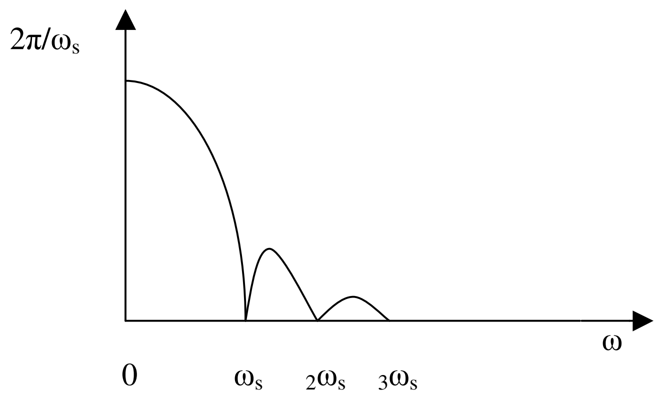


Fig 1. Magnitude response of ZOH device.

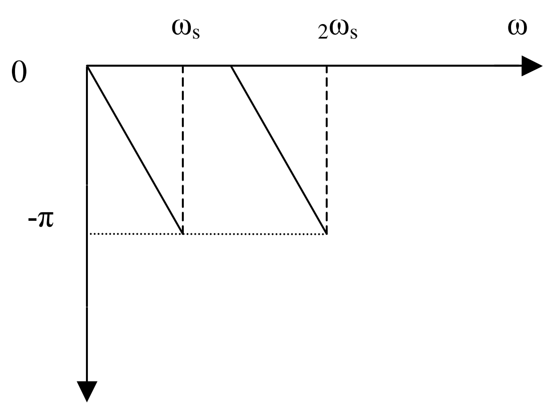


Fig.2.Phase response of ZOH device

63. When can the Z-transform of the system be directly obtained from s-domain transfer function?

When the input to the system is an impulse sampled signal, the z-transfer function can be directly obtained from by taking z-transform of the s-domain transfer function .

64. How is the s-plane mapped onto z-plane? (or) What is the relation between s and z domain?

The transformation s=(1/T)ln z maps the s-plane into the z-plane.Every section of jω axis of length $N\omega_s$ of s-plane maps into the unit circle in the anti-clockwise direction, where N is an integer and ω_s is sampling frequency.Every strip in s-plane of width ω_s, maps into the interior of the unit circle.The is shown in figure.

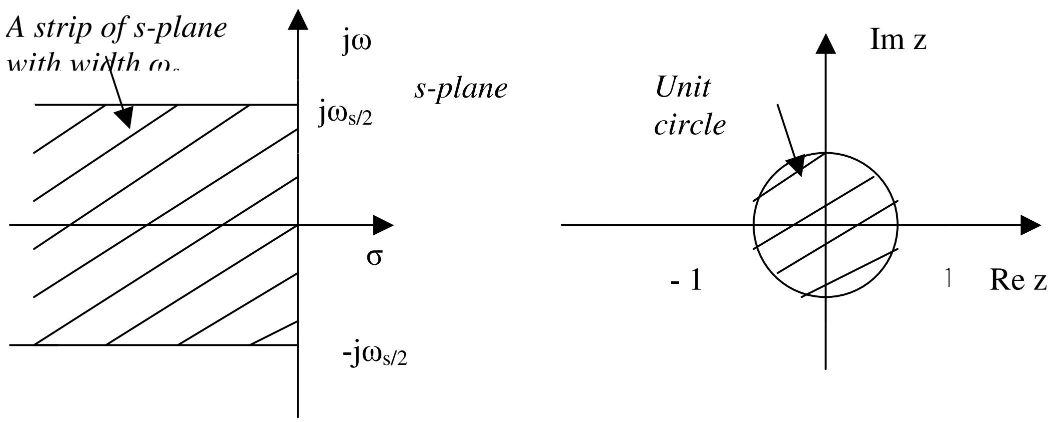


Fig. Mapping of s-plane onto z-plane

65. What is the stability criterion for sampled data control system?

The stability criterion for sampled data control system states that the system is stable if all the poles of the z-transfer function of the system lie inside the unit circle in z-plane.

66. What are the methods available for stability analysis of sampled data control systems?

1. Jury's stability test
2. Bilinear transformation.
3. Root locus technique.

67. What are the necessary conditions to be satisfied for the stability of the system?

Let F (z) be the characteristic equation of the system.

Now, the necessary conditions to be satisfied for the stability of the system are,

$$F(1) > 0 \text{ and } (-1)^n F(-1) > 0.$$

68. How many rows are formed in the Jury's table and what are the sufficient conditions to be checked from this table for stability?

The Jury's table consists of (2n-1) rows, where n is the order of the system.

From the table (n-1) conditions are checked for ascertaining sufficiency. They are,

$| a_0 | < | a_n |$

$| b_0 | > | b_{n-1} |$

$| c_0 | > | c_{n-2} |$

$\vdots$

$| r_0 | > | r_2 |$

69. What are the advantages of state space analysis?

It can be performed with initial conditions. The variables used to represent the system can be any variables in the system.

70. What are the drawbacks in transfer function model analysis?

It is defined under zero initial conditions. It is applicable to linear time invariant systems. It is restricted to signal input and output systems.

71. What is state and state variable?

The state is the condition of a system at any time instant. A set of variables which describes the state of the system at any time instant are called state variables.

72. What is state diagram?

The pictorial representation of the state model of the system is called state diagram.

73. What are phase variables?

The phase variables are defined as those particular state variables which are obtained from one of the system variable and its derivatives. Usually the variable used is the system output and the remaining state variables are the derivatives of the output.

74. What is bush form or companion form of state model?

Here the system matrix A has all 1's in the upper off diagonal and its last row is comprised of the negative of the coefficients of the original differential equation and all other elements are zero.

75. What is canonical form of state model?

The system matrix is a diagonal matrix.

76. State the z plane specifications.

Stability,
Steady state accuracy,
Transient accuracy,
Disturbance rejection,

Insensitivity
Robustness

77. State the ξ locus in the z plane.
It is a logarithmic spiral in the z plane.

78. Explain the mapping of s plane patterns on the z plane.
In the z plane, the closed loop poles must lie on the constant ξ zeta spiral to satisfy peak overshoot requirement, also the poles must lie on constant ω_n curve to satisfy speed of response requirement. The intersection of the two curves provides the preferred pole locations and the design aim is to make the root locus to pass through these locations.

79. Define bandwidth.
It is the frequency at which amplitude ratio has dropped to
$1/\sqrt{2}$ times its zero frequency value.

80. State the causes of control system design with high gain feedback.
Good steady state tracking accuracy
Good disturbance signal rejection
Low sensitivity to process parameter variations

81. State the factors limiting the high gain.
Instability problems, measurement noise appears unattenuated in the controlled output.

82. What is prewarping?
The frequency distortion or warping results in a nonlinear relationship between any 2 frequencies. Hence to compensate the idea is to adjust the critical frequencies in the design. This is called as prewarping.

83. What type of system is referred to as dead beat control system?
The system reaches its steady state value of unity in minimum time (two sampling periods) and there is no ripple in between the sampling instants. This type of response is called as dead beat control systems.

84. What is ringing poles?
The poles near z=-1 are often referred as ringing poles.

85. What is the advantage of microcontroller over microprocessor?
In microcontroller all the peripherals such as RAM, ROM, embedded are inbuilt whereas in microprocessor separately all the components can be added.

86. What is a finite word length effect?
Effects based on finite precision representation of numbers in digital systems.

87. State the causes of finite word length.

Errors due to quantization, errors due to filter co-efficient,
Errors based on to rounding the point multiplications.

88. What is a limit cycle?

A periodic oscillation in a nonlinear system is called a limit cycle.

89. Mention the two different approaches for the design of digital algorithms.

Discretization of analog design
Direct digital design

90. Define the recursive realizing of digital system.

The current output sample is a function of past outputs and present and past input samples. This type of digital system is called infinite impulse response IIR system.

91. What is nonrecursive realization of digital system?

The current output sample is a function of present and past values of the input. The impulse response of the digital system is limited to a finite number of samples defined over a finite range of time intervals. This type of digital system is called as finite impulse response FIR system.

92. State noninteracting controllers.

If the derivative and integral modes operate independently of each other (although proportional gain affects all the 3 modes) is called noninteracting controllers.

93. What are the functions in the digital temperature control system?

Sampling of temperature signal at an appropriate rate.
Transfer of the measurement signal into the computer
Comparison of the measured temperature with a stored desired temperature to form an error signal
Transfer of the output signal through the interface to the power control unit.

94. What is an encoder?

The encoder maps each quantized sample value into a digital word.

95. Mention the operations performed in A/D converter?

Sampling, quantization and coding.

96. Define resolution.

The smallest change in the input signal that will produce a change in the output signal.

97. What type of sampling is commonly used in digital control system?

Uniform sampling i.e., sample values of the analog signals are extracted at equally spaced sampling instants.

98. What is a decoder?

The decoder maps each digital word into a sample value of signal in discrete time form.

99. Mention the operations performed in a D/A converter.
Decoding , zero order hold

100. State the basic discrete time signals.
Unit sample sequence, unit step sequence and sinusoidal sequence.