

**Unit - I****Chapter 1 : Fundamentals of Operational Amplifier
(Op-Amp) 1-1 to 1-26**

Syllabus : Operational amplifier, Equivalent circuit, Circuit symbols and terminals, Op-Amp IC-741 pin diagram and pin function, Op-Amp parameters : Input offset voltage, Input offset current, Input bias current, Differential input resistance, Input capacitance, Input voltage range, Offset voltage adjustment range, Common Mode Rejection Ratio (CMRR), Supply Voltage Rejection Ratio (SVRR), Slew rate, Large signal voltage gain, Supply voltage, Supply current, Output voltage swing, Gain bandwidth product, Output short circuit current. Transfer characteristics - Ideal and practical voltage transfer curves. Op-Amp configurations : Open loop and closed loop, Virtual ground concept, Features, Pin diagram and pin function of dual Op-Amp IC 747.

1.1	Introduction	1-1	1.6	Block Diagram of a Typical OP-AMP	1-5
1.1.1	Applications of OP-AMP	1-1	1.7	Definitions of OP-AMP Parameters (Characteristics)	1-6
1.2	Why is it Called Operational Amplifier ?	1-1	1.7.1	Open Loop Voltage Gain (A_v)	1-6
1.2.1	Advantages of OP-AMP Over Conventional Amplifiers	1-2	1.7.2	Differential Input Resistance (R_i)	1-6
1.3	The Operational Amplifier Circuit Symbol and Terminals	1-2	1.7.3	Output Resistance (R_o)	1-6
1.3.1	Symbol and Terminals	1-2	1.7.4	Input Capacitance	1-6
1.3.2	DC Power Supply for an OP-AMP	1-2	1.7.5	Input Offset Voltage (V_{ios})	1-6
1.4	Ideal Differential Amplifier	1-3	1.7.6	Output Offset Voltage	1-7
1.4.1	Block Diagram of Ideal Differential Amplifier	1-3	1.7.7	Input Bias Current (I_B)	1-7
1.4.2	Differential Mode Signal	1-3	1.7.8	Input Offset Current (I_{ios})	1-7
1.4.3	Common Mode Signal	1-3	1.7.9	Common Mode Rejection Ratio (CMRR)	1-8
1.4.4	Differential Gain A_d	1-3	1.7.10	Power Supply Rejection Ratio (PSRR)	1-8
1.4.5	Common Mode Gain	1-4	1.7.11	Slew Rate	1-9
1.4.6	Common Mode Rejection Ratio (CMRR)	1-4	1.7.12	Bandwidth	1-9
1.4.7	Types of Differential Amplifier	1-4	1.7.13	Gain Bandwidth Product ..	1-9
1.5	Equivalent Circuit of an OP-AMP	1-4	1.7.14	Large Signal Voltage Gain	1-10
			1.7.15	Output Voltage Swing	1-10
			1.7.16	Output Short Circuit Current	1-10
			1.7.17	Supply Voltages	1-10
			1.7.18	Supply Current	1-10
			1.7.19	Offset Voltage Adjustment Range	1-10
			1.7.20	Input Voltage Range	1-10
			1.7.21	Parameters to be Considered for Various Applications	1-10
			1.8	The Ideal OP-AMP	1-11
			1.8.1	Important Characteristics of the Ideal OP-AMP	1-12
			1.9	Voltage Transfer Characteristics of an Ideal OP-AMP	1-13



1.9.1	Voltage Transfer Characteristics of a Practical OP-AMP	1-13
1.10	OP-AMP IC 741	1-14
1.10.1	Features of IC 741	1-14
1.10.2	Pin Configuration and Pin Functions	1-14
1.10.3	Other Packages of OP-AMP	1-15
1.10.4	Important Information about OP-AMP 741	1-15
1.10.5	Maximum Ratings	1-15
1.10.6	Comparison of an Ideal OP-AMP and IC 741	1-15
1.11	Open Loop and Closed Loop Configurations of OP-AMP	1-16
1.11.1	Open Loop Configuration of OP-AMP ..	1-16
1.11.2	OP-AMP in Closed Loop Configurations	1-16
1.11.3	Comparison of Open Loop and Closed Loop Configurations	1-17
1.12	Open Loop Configurations of an OP-AMP	1-17
1.12.1	Differential Amplifier in the Open Loop Mode	1-18
1.12.2	Inverting Amplifier in Open Loop Mode	1-18
1.12.3	Non-inverting Amplifier in the Open Loop Mode	1-19
1.12.4	Why an Open Loop Configuration is Not Suitable for Linear Applications ?	1-20
1.13	Basic Closed Loop Configurations	1-21
1.13.1	Concept of Virtual Short and Virtual Ground	1-21
1.13.2	Virtual Short	1-21
1.13.3	Virtual Ground	1-22
1.14	Dual OP-AMP IC 747	1-22
1.15	MSBTE Questions and Answers	1-23
1.16	I-Scheme Questions and Answers	1-25
	• Review Questions	1-23

Unit - II**Chapter 2 : Applications of Op-Amp****2-1 to 2-32**

Syllabus : Closed loop configuration, Modes of operations : Inverting and non inverting, Differential amplifier, Unity gain amplifier (Voltage follower), Arithmetic operations : Addition, Scaling, Averaging, Subtraction, Integrator, Differentiator, Concept of frequency compensation of OP-AMP and offset nulling.

2.1	Closed Loop Configurations	2-1
2.1.1	The Inverting Amplifier	2-1
2.1.2	Non-Inverting Amplifier	2-2
2.1.3	Comparison of the Amplifier Configurations	2-3
2.1.4	Solved Examples on Inverting and Non-inverting Amplifiers	2-3
2.2	The Voltage Follower (Unity Gain Buffer)	2-7
2.2.1	Features of a Voltage Follower Circuit ...	2-7
2.2.2	Applications	2-7
2.2.3	Inverter (Sign Changer)	2-7
2.3	OP-AMP used as an Adder	2-8
2.3.1	Inverting Adder or Inverting Summing Amplifier	2-8
2.3.2	Scaling or Weighted Amplifier	2-9
2.3.3	Averaging Circuit	2-9
2.3.4	Non-Inverting Adder	2-9
2.3.5	Non-Inverting Averaging Amplifier	2-10
2.3.6	Solved Examples on Inverting and Non-inverting Adders	2-11
2.4	Difference Amplifier and Subtractor	2-15
2.4.1	Difference Amplifier	2-15
2.4.2	Subtractor	2-15
2.4.3	Examples on Difference Amplifier and Subtractor	2-16
2.5	Integrator	2-18
2.5.1	Active Integrator using OP-AMP	2-18
2.5.2	Ideal (Basic) Integrator Circuit	2-18
2.5.3	Input and Output Waveforms	2-19



2.5.4	Problems Associated with the Basic Integrator	2-20	3.1	Introduction	3-1
2.5.5	Practical Integrator	2-21	3.2	Voltage to Current (V to I) Converters	3-1
2.5.6	Advantages of Active Integrator	2-22	3.2.1	Voltage to Current Converter with Floating Load	3-1
2.5.7	Disadvantages of Active Integrator	2-22	3.2.2	Applications of V-I Converter with a Floating Load	3-2
2.5.8	Applications of an Integrator	2-22	3.2.3	Voltage to Current Converter with Grounded Load	3-2
2.5.9	Design Procedure for an Integrator	2-22	3.2.4	Applications	3-2
2.6	Differentiator	2-22	3.3	Current to Voltage Converter (I to V)	3-2
2.6.1	Differentiator using OP-AMP (Active Differentiator)	2-22	3.3.1	Applications of I to V Converter	3-3
2.6.2	Basic (Ideal) Differentiator Circuit	2-22	3.4	Instrumentation Amplifier (I.A.)	3-3
2.6.3	Input and Output Voltage Waveforms	2-23	3.4.1	Need of Signal Conditioning and Processing	3-3
2.6.4	Practical Differentiator	2-25	3.4.2	Block Diagram of an Instrumentation Amplifier	3-4
2.6.5	Applications of a Differentiator	2-26	3.4.3	Requirements or Characteristics of an Instrumentation Amplifier	3-4
2.6.6	Steps to Design a Practical Differentiator	2-26	3.4.4	Instrumentation Amplifier Circuits	3-4
2.6.7	Comparison of Active Integrator and Differentiator	2-26	3.4.5	I.A. using One OP-AMP	3-4
2.7	Frequency Response of an OP-AMP	2-28	3.4.6	Instrumentation Amplifiers with Dual OP-AMPs	3-5
2.7.1	Frequency Response of an Uncompensated OP-AMP	2-28	3.4.7	The Three OP-AMP Instrumentation Amplifier	3-6
2.7.2	Concept of Frequency Compensation	2-28	3.4.8	Advantages of Instrumentation Amplifiers (3 OP-AMP)	3-7
2.8	Input Offset Voltage Compensation (Offset Nulling)	2-29	3.4.9	Applications of Instrumentation Amplifier	3-7
2.9	MSBTE Questions and Answers	2-30	3.4.10	Examples on Instrumentation Amplifier	3-8
2.10	I-Scheme Solved Examples	2-32	3.5	IC LM 324 Low Power Quad OPAMP	3-8
2.11	I-Scheme Questions and Answers	2-32	3.5.1	General Description	3-8
	• Review Questions	2-29	3.5.2	Special Characteristics	3-9
Unit - III			3.5.3	Connection Diagram	3-9
Chapter 3 : Linear Applications of Op-Amp 3-1 to 3-20			3.5.4	Pin Diagram	3-9
Syllabus : OP-Amp as an instrumentation amplifier : Working, Derivation of output voltage, IC LM 324 - Pin configuration, Specifications and applications. Voltage to current converter with floating and grounded load, Current to voltage converter, Sample and hold circuit, Logarithmic and antilogarithmic amplifiers using diodes, Analog divider and analog multiplier.			3.5.5	Features	3-9



3.5.6	Absolute Maximum Ratings (Specifications) of LM 324	3-9
3.6	Logarithmic Amplifiers	3-10
3.6.1	Basic Equation for Log and Antilog Amplifiers	3-10
3.6.2	Basic Log Amplifier using Diode	3-10
3.6.3	Disadvantages of Basic Log Amplifier	3-11
3.6.4	Temperature Compensated Log Amplifier	3-11
3.6.5	Applications of Log Amplifier	3-12
3.7	Antilog Amplifier	3-12
3.7.1	Basic Antilog Amplifier using Diode	3-12
3.7.2	Temperature Compensated Antilog Amplifier	3-13
3.7.3	Applications of an Antilog Amplifier	3-13
3.8	Sample and Hold Circuit	3-13
3.8.1	Basic Sample and Hold Circuit	3-13
3.8.2	Sample and Hold Circuit using OP-AMP	3-14
3.8.3	Applications of Sample and Hold Circuit	3-14
3.8.4	Performance Parameters of SHA	3-15
3.8.5	IC Sample and Hold Amplifier	3-15
3.9	Analog Multipliers	3-15
3.9.1	Analog Multiplication Techniques	3-16
3.9.2	Multipliers using Log / Antilog Amplifiers	3-16
3.9.3	Analog Divider	3-16
3.9.4	Analog Divider using Log/Antilog Amplifiers	3-17
3.9.5	Squaring Circuit using Log Amplifier	3-17
3.10	MSBTE Questions and Answers	3-18
3.11	I-Scheme Questions and Answers	3-19
	• Review Questions	3-18

Unit - III**Chapter 4 : Comparators****4-1 to 4-21**

Syllabus : Comparators, IC LM 710 Circuit diagram and operation of : Zero crossing detector, Schmitt trigger, Window detector, Phase detector, Active peak detector, Peak to peak detector.

4.1	Introduction	4-1
4.2	OP-AMP as a Comparator	4-1
4.2.1	Transfer Characteristics	4-1
4.2.2	Types of Comparator	4-2
4.2.3	Comparator Applications	4-2
4.3	Non-Inverting Comparator	4-2
4.3.1	Transfer Characteristics of Non-Inverting Comparator	4-3
4.3.2	Transfer Characteristics for Zero or Negative Reference	4-3
4.4	Inverting Comparator	4-3
4.4.1	Operation of the Circuit	4-3
4.4.2	Transfer Characteristics of an Inverting Comparator	4-4
4.4.3	Transfer Characteristics for Zero and Negative Reference Voltage	4-4
4.5	Zero Crossing Detector (ZCD)	4-5
4.5.1	Inverting ZCD	4-5
4.5.2	Non-Inverting ZCD	4-5
4.5.3	Window Comparators (Detector)	4-6
4.6	Comparison of Inverting and Non-Inverting Type Comparators	4-8
4.7	IC Comparators	4-9
4.7.1	Features of Comparator ICs	4-9
4.7.2	LM 710 Voltage Comparator	4-9
4.7.3	Requirements of an OP-AMP to be used as a Comparator	4-10
4.8	Schmitt Trigger (Regenerative Comparator)	4-10



4.8.1	Types of Schmitt Trigger	4-10	5.4	Filter Characteristic Terms	5-2
4.8.2	Inverting Schmitt Trigger	4-10	5.4.1	Frequency Response	5-2
4.8.3	Non-inverting Schmitt Trigger	4-12	5.4.2	- 3 dB Frequency f_{-3dB}	5-3
4.8.4	Hysteresis	4-13	5.4.3	Passband and Stopband	5-3
4.8.5	Comparison of Comparator and Schmitt Trigger	4-14	5.4.4	Roll off Rates	5-4
4.8.6	Advantages of Schmitt Trigger Over the Conventional Comparators	4-14	5.4.5	Order of Filter	5-5
4.9	Applications of Schmitt Trigger	4-14	5.4.6	Roll off Rate and Number of Poles (Order)	5-5
4.10	Solved Examples	4-15	5.4.7	Q and BW of a Filter	5-6
4.11	Peak Detector using OP-AMP	4-16	5.5	Filter Classification Based on its Frequency Response	5-6
4.11.1	Positive Peak Detector	4-16	5.6	Ideal and Actual Frequency Response Characteristics of Filters	5-7
4.11.2	Negative Peak Detector	4-17	5.6.1	Frequency Response Characteristics of a Low-pass Filter	5-7
4.11.3	Peak to Peak Detector	4-17	5.6.2	Frequency Response Characteristics of a High-pass Filter	5-7
4.12	Phase Detector	4-18	5.6.3	Frequency Response Characteristics of a Bandpass Filter	5-8
4.13	University Questions and Answers	4-19	5.6.4	Frequency Response of an All Pass Filter	5-8
4.14	I-Scheme Questions and Answers	4-21	5.6.5	Bandstop Filter	5-8
	• Review Questions	4-18	5.7	Butterworth Low Pass Filters	5-8
Unit - IV			5.7.1	First Order Butterworth Low-pass Filter	5-8
Chapter 5 : Filters			5.7.2	Expression for the Gain of the Filter	5-9
5-1 to 5-37			5.7.3	Second Order Low-pass Butterworth Filter	5-10
Syllabus : Filters and its classification, Merits and demerits of active filters over passive filters, Filter characteristic terms : Order of filter, Cut off frequency, Passband, Stopband, Centre frequency, Roll off rate, Bandwidth, Q factor, Filter types and its frequency response : Low pass (First order and second order), Highpass (First order and second order) Bandpass (Wide and narrow), Band reject (Wide and narrow), All pass filter.					
5.1	Introduction	5-1	5.8	Butterworth High Pass Filters	5-16
5.2	Classification of Filters	5-1	5.8.1	First Order Butterworth High-pass Filter	5-16
5.2.1	Passive or Active Filters	5-1	5.8.2	Expression for the Filter Gain	5-16
5.3	Merits and Demerits of Active Filters Over Passive Filters	5-2	5.8.3	Design Procedure (First Order HPF)	5-17
5.3.1	Merits of Active Filters	5-2	5.8.4	Second Order High-pass Butterworth Filter	5-18
5.3.2	Demerits of Active Filters	5-2			



5.9	Bandpass Filters	5-20	6.3.4	Disadvantages of Phase Shift Oscillator	6-4
5.9.1	Wide Bandpass Filter	5-21	6.3.5	Examples on RC Phase Shift Oscillator	6-4
5.9.2	Narrow Band-Pass Filter	5-22	6.4	Wien Bridge Oscillator	6-5
5.10	Band-Reject Filters	5-26	6.4.1	The Wien Bridge Circuit	6-5
5.10.1	Types of Band-reject Filters	5-26	6.4.2	Feedback Factor (β) and Gain (A)	6-6
5.10.2	Wide-Band-Reject Filter	5-26	6.4.3	Wien Bridge Oscillator using OP-AMP ...	6-6
5.10.3	Narrow-Band-Reject (Notch) Filter	5-27	6.4.4	Advantages of Wien Bridge Oscillator ...	6-7
5.11	All Pass Filter	5-31	6.4.5	Disadvantages	6-7
5.11.1	Applications of All Pass Filters	5-31	6.4.6	Example on Wien Bridge Oscillator	6-7
5.12	MSBTE Questions and Answers	5-32	6.5	LC Oscillators	6-7
5.13	I-Scheme Solved Examples.....	5-37	6.6	Hartley Oscillator using OP-AMP	6-8
5.14	I-Scheme Questions and Answers	5-37	6.6.1	Advantages of Hartley Oscillator	6-8
	• Review Questions	5-32	6.6.2	Applications	6-8

Unit - IV

Chapter 6 : Oscillators 6-1 to 6-12

Syllabus : Oscillator types using IC 741 : Phase shift oscillator, Wien bridge oscillator, Colpitts oscillator, Hartley oscillator.

6.1	Concept of Oscillators	6-1	6.7	Colpitt's Oscillator using OP-AMP	6-8
6.2	Concept of Positive Feedback	6-1	6.7.1	Frequency Stability	6-9
6.2.1	Expression for the Gain with Positive Feedback (A_f)	6-2	6.7.2	Advantages of Colpitt's Oscillator	6-9
6.2.2	Oscillator Principle	6-2	6.7.3	Disadvantages	6-9
6.2.3	Barkhausen Criteria	6-2	6.7.4	Application	6-9
6.2.4	Block Diagram of an Oscillator	6-2	6.8	Applications of LC Oscillators	6-9
6.2.5	Types of Oscillators using OP-AMP 741	6-3	6.9	Comparisons	6-9
6.3	RC Phase Shift Oscillator	6-3	6.9.1	Comparisons of LC and RC Oscillators	6-9
6.3.1	RC Network for the Phase Shift Oscillator	6-3	6.9.2	Comparison of LC Oscillators	6-10
6.3.2	RC Phase Shift Oscillator using OP-AMP	6-3	6.9.3	General Applications of Oscillator	6-10
6.3.3	Advantages of Phase Shift Oscillator	6-4	6.10	MSBTE Questions and Answers	6-10
			6.11	I-Scheme Questions and Answers	6-12
				• Review Questions	6-10

Unit - V

Chapter 7 : Timer IC 555 7-1 to 7-22

Syllabus : IC 555 : Block diagram of timer, Pin diagram and functions, Astable, Monostable, Bistable multivibrator, Schmitt trigger and voltage controlled oscillator.



7.1	Introduction	7-1
7.2	Basics of Timer IC 555	7-1
7.3	Block Diagram of IC 555	7-1
7.3.1	Pin Diagram of Timer IC NE 555	7-2
7.4	Features for IC 555	7-4
7.5	Modes of Operation of IC 555 (Multivibrators)	7-4
7.6	Monostable Multivibrator using 555 [IC 555 as a Timer]	7-4
7.6.1	Operation of the Monostable Multivibrator	7-5
7.6.2	Conditions for Satisfactory Operation	7-7
7.6.3	Expression for the ON TIME or Pulse Width of the Output Voltage	7-7
7.6.4	Applications of a Monostable Multivibrato	7-7
7.6.5	Examples on Monostable Multivibrator	7-7
7.7	Astable Multivibrator using IC 555 [Free Running Multivibrator]	7-9
7.7.1	Operation of Astable Multivibrator	7-10
7.7.2	One Cycle Period and Frequency of the Output	7-12
7.7.3	Expression for Duty Cycle (D)	7-12
7.8	Applications of Astable Multivibrator	7-12
7.8.1	Square Wave Oscillator	7-13
7.8.2	IC 555 as Voltage Controlled Oscillator (VCO)	7-14
7.8.3	Schmitt Trigger using IC 555	7-14
7.8.4	Solved Examples on Astable Multivibrator	7-15
7.9	A Bistable Multivibrator or Flip-flop using IC 555	7-19
7.10	Comparison of Astable, Monostable and Bistable Multivibrators	7-20

7.11	MSBTE Questions and Answers	7-20
7.12	I-Scheme Questions and Answers	7-22
	• Review Questions	7-20

Unit - V

Chapter 8 : Phase Lock Loops (PLL) 8-1 to 8-9

Syllabus : Phase lock loop (PLL) : Block diagram and its operation, Lock range and capture range, Applications of PLL : PLL as multiplier, FM demodulator, IC 565 : Pin diagram and function.

8.1	Introduction	8-1
8.2	Principle of Operation of PLL	8-1
8.2.1	Some Important Definitions Related to PLL	8-2
8.2.2	PLL Transfer Curve	8-2
8.3	Monolithic Phase-Locked Loop	8-3
8.4	PLL IC - SE/NE 565	8-3
8.4.1	Functional Block Diagram and Pin Diagram	8-3
8.4.2	Connection Diagram of PLL 565	8-4
8.4.3	Important Features of 565 PLL	8-5
8.5	Function Generator / Voltage Controlled Oscillator IC 566	8-6
8.5.1	Functional Block Diagram	8-6
8.5.2	Typical Connection Diagram	8-7
8.6	Applications of PLL	8-7
8.6.1	PLL as Frequency Multiplier	8-7
8.6.2	PLL as FM Demodulator	8-8
8.7	MSBTE Questions and Answers	8-9
8.8	I-Scheme Questions and Answers	8-9
	• Review Questions	8-8

