

Module 1

Chapter 1 : Semiconductor Devices 1-1 to 1-42

Syllabus : Review of diodes, V-I characteristics and applications of : Rectifier diode, Zener diode, LED, Photodiode; SCR V-I characteristics, UJT triggering circuit, Turning-off of a SCR (preliminary discussion), Basics of Gate Turn Off (GTO), Structure and V-I characteristics of Triac (modes of operation not needed) and Diac, Applications of Triac-Diac circuit

<p>1.1 Introduction to Power Electronics1-3</p> <p> 1.1.1 Principle of Power Electronics1-3</p> <p>1.2 Types of Power Electronic Circuits1-3</p> <p> 1.2.1 Classification of Power Electronic Circuits1-3</p> <p> 1.2.2 Rectifiers1-3</p> <p> 1.2.3 AC to DC Converter / Controlled Rectifiers1-3</p> <p> 1.2.4 DC to AC Converter / Inverters1-4</p> <p> 1.2.5 DC to DC Converter / Choppers1-4</p> <p> 1.2.6 AC Regulators (AC Controlled)1-4</p> <p>1.3 Power Semiconductor Devices1-4</p> <p> 1.3.1 Need of High Power Semiconductor Devices1-4</p> <p>1.4 Power Diodes1-5</p> <p> 1.4.1 Types of Power Diodes1-5</p> <p>1.5 Rectifier Diodes1-5</p> <p> 1.5.1 Characteristics of Rectifier Diodes1-5</p> <p> 1.5.2 Principle of Operation1-6</p> <p> 1.5.3 V-I Characteristics of a Rectifier Diode .1-7</p> <p> 1.5.4 Applications of Rectifier Diodes1-8</p> <p>1.6 Zener Diode1-9</p> <p> 1.6.1 Principle of Operation1-9</p> <p> 1.6.2 Circuit Symbol and Biasing of a Zener Diode1-9</p>	<p> 1.6.3 V-I Characteristics of a Zener Diode1-9</p> <p>1.7 Applications of Zener Diode1-10</p> <p>1.8 Light Emitting Diodes (LED)1-10</p> <p> 1.8.1 Construction of LED1-11</p> <p> 1.8.2 Principle of LED Operation1-11</p> <p> 1.8.3 LED Voltage and Current (LED Biasing)1-11</p> <p> 1.8.4 Applications of LED1-12</p> <p>1.9 Photodiode1-12</p> <p> 1.9.1 Operation of Photodiode1-12</p> <p> 1.9.2 Photodiode Characteristics1-12</p> <p> 1.9.3 Applications of Photodiode1-13</p> <p>1.10 Silicon Controlled Rectifier (SCR)1-13</p> <p> 1.10.1 Important Features of SCR1-13</p> <p> 1.10.2 Construction of SCR1-14</p> <p> 1.10.3 I-V Characteristics (Static Characteristics)1-14</p> <p> 1.10.4 Important Terms1-15</p> <p> 1.10.5 Difference between holding and latching currents1-16</p> <p> 1.10.6 How to Turn off a Conducting SCR ?1-16</p> <p> 1.10.7 Operation of SCR1-16</p> <p> 1.10.8 Two Transistor Analogy of SCR1-17</p> <p> 1.10.9 SCR as a Switch1-18</p> <p> 1.10.10 Applications of SCR1-18</p> <p>1.11 Bidirectional Triode SCR (Triac)1-18</p> <p> 1.11.1 Construction of a Triac1-18</p> <p> 1.11.2 V-I Characteristics of Triac1-19</p> <p> 1.11.3 Comparison of SCR and Triac1-20</p> <p>1.12 DIAC1-20</p> <p> 1.12.1 Construction of Diac1-21</p> <p> 1.12.2 I-V Characteristics of a Diac1-21</p>
---	---



1.12.3	DIAC Applications	1-22	1.17.4	AC Gate Triggering	1-31
1.12.4	Comparison of Diac and Triac	1-22	1.17.5	AC Gate Triggering Circuits	1-31
1.13	Unijunction Transistor (UJT)	1-22	1.18	Basic Triggering Circuits for Thyristors	1-31
1.13.1	Construction	1-22	1.18.1	Simple Resistor Triggering Circuit	1-31
1.13.2	Equivalent Circuit of UJT	1-23	1.18.2	Basic UJT Relaxation Oscillator	1-33
1.13.3	Intrinsic Standoff Ratio (η)	1-23	1.18.3	Synchronized UJT Triggering Circuit	1-34
1.13.4	Operation of UJT	1-23	1.19	Triac Triggering using Diac.....	1-36
1.13.5	V-I Characteristic of UJT	1-23	1.19.1	Light Intensity Control using Triac	1-37
1.13.6	Applications of UJT	1-24	1.19.2	Fan Regulator using Triac	1-38
1.14	Gate Turn Off SCR (GTO)	1-24	1.20	Turn Off Process of SCR (Commutation).....	1-38
1.14.1	Basic Structure of GTO	1-24	1.21	Introduction to Commutation	1-39
1.14.2	I-V Characteristics of GTO	1-25	1.22	Commutation Techniques	1-39
1.14.3	GTO Equivalent Circuit	1-25	1.22.1	Natural Commutation	1-39
1.14.4	GTO Operation	1-25	1.22.2	Forced Commutation	1-40
1.14.5	GTO Turnoff	1-25	1.22.3	Comparison of Natural and Forced Commutation	1-41
1.14.6	Difference between Gating Characteristics of GTO and SCR	1-26	1.23	University Questions and Answers	1-42
1.14.7	Applications of GTO	1-26		• Review Questions.....	1-41
1.15	Turn on Methods of SCR	1-26	Module 1		
1.15.1	Delay Angle or Firing Angle or Phase Angle (α)	1-27	<hr/>		
1.16	Turn ON Methods	1-27	Chapter 2 : Power Transistors 2-1 to 2-18		
1.16.1	Thermal Triggering	1-27	Syllabus : Characteristics of power BJT, Power MOSFET, IGBT; Comparison of SCR, Triac, Power BJT, Power MOSFET, IGBT.		
1.16.2	Optical or Illumination Triggering	1-27	2.1	Introduction	2-2
1.16.3	Forward Voltage Triggering	1-28	2.1.1	Classification of Power Transistors	2-2
1.16.4	dv/dt Triggering	1-28	2.1.2	Power BJT	2-2
1.16.5	dv/dt Protection (Snubber Circuit)	1-29	2.2	Construction of Power BJT	2-2
1.16.6	Gate Triggering	1-29	2.2.1	Operation of Power Transistor	2-3
1.17	Types of Gate Triggering	1-30	2.3	I-V Characteristics of the Power BJT	2-4
1.17.1	DC Gate Triggering	1-30	2.3.1	Driving Circuit for a Power BJT	2-6
1.17.2	Pulsed Gate Triggering of SCR	1-30	2.4	Merits, Demerits and Applications of a Power BJT	2-7
1.17.3	Comparison of DC Triggering and Pulse Triggering	1-31			

2.5 Power MOSFET2-8

 2.5.1 Construction of a Power MOSFET2-8

 2.5.2 DC Biasing2-9

 2.5.3 Principle of Operation 2-10

 2.5.4 I-V Characteristics
 (Static Characteristics) 2-11

 2.5.5 Gate Drive Circuit for Power
 MOSFET 2-12

2.6 Merits, Demerits and Applications of Power
MOSFET 2-13

 2.6.1 Merits of a Power MOSFET 2-13

 2.6.2 Demerits of a Power MOSFET 2-13

 2.6.3 Applications of Power MOSFETs 2-14

2.7 Insulated Gate Bipolar Transistor (IGBT) 2-14

 2.7.1 Features of IGBT 2-14

2.8 Construction of IGBT 2-14

2.9 I-V Characteristics of IGBT..... 2-15

2.10 Principle of Operation of IGBT 2-16

2.11 Merits, Demerits and Applications of IGBT 2-17

2.12 Comparison of SCR, TRIAC, BJT, MOSFET
and IGBT 2-17

 • **Review Questions** 2-18

Module 2

Chapter 3 : Phase Controlled Rectifiers 3-1 to 3-14

Syllabus : Full wave controlled rectifier using SCRs (semi controlled, fully controlled) with R load only.

3.1 Controlled Rectifiers3-2

 3.1.1 Principle of Phase Angle Control3-2

3.2 Classification of Controlled Rectifiers3-3

3.3 Half Wave Controlled Rectifier3-4

 3.3.1 Drawbacks of HWCR3-5

3.4 Semiconductor or Half Controlled Rectifier3-6

3.4.1 Operation with the Resistive Load
(Asymmetric Configuration) 3-6

3.4.2 The average load voltage ($V_{L,dc}$) 3-8

3.4.3 Advantages of Semiconverters 3-8

3.4.4 Disadvantages of Semiconverters 3-8

3.4.5 Application 3-9

3.5 Full Controlled Rectifier 3-9

 3.5.1 Operation of Full Converter with Resistive
 Load 3-9

 3.5.2 Average Load Voltage3-11

 3.5.3 Advantages of Full Converter3-11

 3.5.4 Disadvantages of Full Converter3-11

 3.5.5 Application3-11

 3.5.6 Comparison of Semiconverter and Full
 Converter3-11

 3.5.7 Applications of Controlled Rectifiers ..3-12

 3.5.8 Comparison of Controlled H.W.R. and
 Controlled F.W.R.3-12

3.6 University Questions and Answers3-14

 • **Review Questions**..... **3-13**

Module 2

Chapter 4 : Inverters 4-1 to 4-12

Syllabus : Basic principle of single phase and three phase bridge inverters.

4.1 Basic Principle of Inverter..... 4-2

4.2 Classification of Inverters 4-2

 4.2.1 Classification Based on the Nature of
 Source 4-2

 4.2.2 Classification Based on the Configuration
 of the Inverter 4-2

 4.2.3 Classification Based on the Nature of
 Output Waveform 4-2

 4.2.4 Classification Based on the Power
 Semiconductor Device Used 4-3



4.3	Single Phase Bridge Inverter	4-3	5.2.3	Open Loop Control of DC Motor	5-4
	4.3.1 Operation with Resistive Load	4-3	5.2.4	Closed Loop Speed Control of DC Motor	5-4
4.4	Operation with RL Load	4-4	5.3	Speed Control of DC Motors using Thyristor Technology	5-5
	4.4.1 Applications of Single Phase Inverters	4-6	5.3.1	Closed Loop Armature Voltage Control	5-5
4.5	Three Phase Inverters	4-6	5.3.2	Closed Loop Field Current Control	5-6
4.6	Three Phase Bridge Inverter	4-6	5.4	Closed Loop Speed Control of DC Motor with Inner Loop	5-6
	4.6.1 180° Mode of Operation	4-7	5.5	Introduction to AC Motor Control	5-7
	4.6.2 180° Mode with a Star Connected Resistive Load	4-8	5.6	A Three Phase Induction Motor	5-7
	4.6.3 120° Mode of Conduction (with Star Connected Resistive Load)	4-9	5.6.1	Synchronous Speed (N_s)	5-8
	4.6.4 Applications of Three Phase Inverters	4-11	5.6.2	Slip s	5-8
4.7	Comparison of 1 Phase and 3 Phase Inverters	4-11	5.6.3	Actual Speed N	5-8
	• Review Questions	4-11	5.6.4	Torque Slip Characteristics of Induction Motor	5-8

Module 2

Chapter 5 : DC and AC Motor Control 5-1 to 5-16

Syllabus : Block diagram of closed loop speed control of DC motors, Block diagrams including rectifier and inverter for speed control of AC motors (frequency control only).

5.1	Introduction	5-2	5.7	Speed Control of Induction Motors	5-9
	5.1.1 Basic Elements of Electric Drives	5-2	5.8	Stator Voltage and Frequency Control (Constant V/f Control)	5-10
	5.1.2 Requirements of Adjustable Speed Drives	5-2	5.8.1	Implementation of Variable Voltage Variable Frequency Control	5-11
	5.1.3 Advantages of Electronic Control	5-2	5.8.2	Constant V/f Control using Inverter	5-12
	5.1.4 Comparison of Conventional Control and Electronic Control	5-3	5.8.3	Constant V/f Control using PWM Inverter (PWM Based VSI Drive)	5-13
5.2	DC Motor Speed Control	5-3	5.9	Closed Loop Control of IM.	5-14
	5.2.1 Speed control of separately excited dc motor	5-3	5.10	Comparison of DC and AC Drives	5-14
	5.2.2 Open Loop or Closed Loop Speed Control	5-3		• Review Questions	5-15

Module 3

Chapter 6 : Operational Amplifiers 6-1 to 6-26

Syllabus : Operational amplifier circuits, Ideal OPAMP behaviour, Common OPAMP ICs; Basic OPAMP circuits, Inverting amplifier, Non-inverting amplifier, Voltage follower (Buffer), Comparator, Instrumentation amplifier, Power OPAMPs.



6.1	Introduction	6-2	6.15.2	Scaling or Weighted Amplifier	6-17
6.1.1	An OP-AMP	6-2	6.15.3	Averaging Circuit	6-17
6.2	OP-AMP Symbol and Terminals	6-2	6.15.4	Difference Amplifier	6-19
6.2.1	Symbol and Terminals	6-2	6.15.5	Subtractor	6-19
6.2.2	DC Power Supply for an OP-AMP	6-3	6.16	Instrumentation Amplifier	6-20
6.3	Ideal Differential Amplifier	6-3	6.16.1	Requirements of an Instrumentation Amplifier	6-21
6.4	Block Diagram of a Typical OP-AMP	6-4	6.16.2	Practical Instrumentation Amplifier	6-22
6.5	Equivalent Circuit of an OP-AMP	6-4	6.16.3	Advantages of Instrumentation Amplifiers	6-22
6.6	OP-AMP Input Modes	6-5	6.16.4	Disadvantages of Instrumentation Amplifier	6-23
6.6.1	Ideal OP-AMP Behaviour	6-6	6.16.5	Applications of Instrumentation Amplifier	6-23
6.7	OP-AMP IC 741 (Common OP-AMP IC)	6-8	6.17	Types of OPAMP	6-23
6.7.1	Pin Configuration	6-8	6.17.1	Power OP-AMPs	6-23
6.7.2	Important Characteristics of IC 741	6-8	6.18	Audio Power Amplifier (IC LM 380)	6-24
6.8	Open Loop Configuration of OP-AMP	6-9	6.18.1	Features of LM 380	6-24
6.9	OP-AMP in Closed Loop Configurations	6-9	6.18.2	Functional Block Diagram	6-24
6.9.1	Negative Feedback in OP-AMP	6-10	6.18.3	Applications of LM 380	6-24
6.10	Concept of Virtual Short and Virtual Ground ...	6-10	6.18.4	Audio Power Amplifier	6-24
6.10.1	Virtual Short	6-10	6.18.5	LM 380 as a High Gain Amplifier	6-25
6.10.2	Virtual Ground	6-11	6.18.6	LM 380 as a Variable Gain Amplifier ...	6-25
6.10.3	Zero Input Current	6-11	6.18.7	LM 380 as Bridge Audio Power Amplifier	6-25
6.11	OP-AMPs with Negative Feedback	6-11	6.19	University Questions and Answers	6-26
6.11.1	Closed Loop Voltage Gain (A_{VF})	6-11		• Review Questions	6-25
6.12	The Inverting Amplifier.....	6-11			
6.12.1	Closed Loop Voltage Gain (A_{VF})	6-12			
6.13	Non-Inverting Amplifier	6-13			
6.13.1	Closed Loop Voltage Gain (A_{VF})	6-13			
6.13.2	Comparison of the Amplifier Configurations	6-14			
6.14	The Voltage Follower (Buffer)	6-15			
6.15	Summing Amplifier or Adder	6-16			
6.15.1	Inverting Adder or Inverting Summing Amplifier.....	6-16			

Module 3

Chapter 7 : Active Filters

7-1 to 7-8

Syllabus : Active first order filters : Low pass and high pass filters.

7.1	Introduction	7-2
7.1.1	Analog or Digital Filters	7-2

7.2 Passive or Active Filters7-2

7.3 Merits and Demerits of Active Filters7-2

 7.3.1 Merits of Active Filters7-2

 7.3.2 Demerits of Active Filters7-3

7.4 Definitions Related to Filters7-3

 7.4.1 Frequency Response7-3

 7.4.2 - 3 dB Frequency $f_{-3\text{dB}}$ 7-3

 7.4.3 Pass band and Stop band7-3

7.5 Filter Types7-4

7.6 Frequency Response of Filters7-4

 7.6.1 Frequency Response of a Low-pass Filter7-4

 7.6.2 Frequency Response of a High-pass Filter7-5

7.7 First Order Low-pass Filter7-5

7.8 First Order High-pass Filter7-6

 • **Review Questions** 7-7

Module 3

Chapter 8 : IC 555 Timer 8-1 to 8-10

Syllabus : IC 555 timer-Operating modes : Monostable, Astable multivibrator.

8.1 IC 555 Timer8-2

 8.1.1 Features of IC NE 5558-2

 8.1.2 Functional Block Diagram of IC NE 5558-2

 8.1.3 Pin-wise Description of Timer IC 5558-2

8.2 Multivibrators8-4

 8.2.1 Classification of Multivibrators8-5

8.3 Monostable Multivibrator using Timer IC 555 (Timer)8-5

 8.3.1 Examples on Monostable Multivibrator8-7

8.3.2 Applications of Monostable Multivibrator8-7

8.4 IC 555 as an Astable Multivibrator8-7

 8.4.1 Frequency of the Output8-8

 8.4.2 Expressions for T_c (or T_{on})8-8

 8.4.3 Expression for T_d (or T_{off})8-9

 8.4.4 Expression for Frequency8-9

 8.4.5 Expression for Duty Cycle (D)8-9

8.5 Applications of Astable Multivibrator8-9

8.6 Comparison of Astable and Monostable Multivibrator8-9

8.7 Applications of IC 5558-10

 • **Review Questions**..... 8-10

Module 4

Chapter 9 : Digital Logic and Logic Families 9-1 to 9-48

Syllabus : Boolean algebra and logic gates, Logic families : Logic levels, Noise immunity, Fan out, Propagation delay, TTL and CMOS logic families, Flip flops : Set Reset (SR), Trigger (T), Clocked F/Fs; Registers, Multiplexer and demultiplexer applications.

9.1 Introduction9-3

 9.1.1 Signals9-3

 9.1.2 Types of Signals9-3

 9.1.3 Analog Signals9-3

 9.1.4 Digital Signals9-3

 9.1.5 Analog and Digital Circuits9-3

 9.1.6 Binary Logic and Logic Levels9-4

9.2 Logic Operators and Logic Gates9-4

 9.2.1 Basic Logical Operations9-5

 9.2.2 Logic Gates9-5

 9.2.3 Classification of Logic Gates9-5

9.3 Logic Families9-5

9.4 NOT Gate or Inverter9-5



9.5	AND Gate	9-6	9.14.5	Sequential Circuits	9-23
9.6	The OR Gate	9-6	9.14.6	Combinational Circuits	9-23
9.7	The NAND Gate	9-7	9.14.7	Comparison of Combinational and Sequential Circuits	9-23
9.8	The NOR Gate	9-7	9.14.8	Technologies	9-23
9.9	Special Type of Gates or Derived Gates	9-8	9.15	Classification of Logic Families	9-23
9.9.1	The EX-OR Gate	9-8	9.16	Characteristics of Digital ICs	9-24
9.9.2	The EX-NOR Gate	9-8	9.16.1	Voltage and Current Parameters	9-25
9.9.3	Examples of IC Gates	9-9	9.16.2	Fan-in and Fan-out	9-26
9.10	Boolean (Binary) Algebra	9-9	9.16.3	Noise Margin	9-26
9.11	Boolean Laws	9-9	9.16.4	Propagation Delay	9-27
9.11.1	Commutative Law	9-9	9.16.5	Power Dissipation	9-28
9.11.2	Associative Law	9-10	9.16.6	Operating Temperature	9-28
9.11.3	Distributive Law	9-10	9.16.7	Figure of Merit (Speed Power Product SPP)	9-28
9.11.4	AND Laws	9-10	9.17	TTL Logic	9-28
9.11.5	OR Laws	9-10	9.17.1	The Multiple Emitter Transistor	9-29
9.11.6	INVERSION Law	9-10	9.17.2	Two Input TTL-NAND Gate (Totem pole Output)	9-29
9.11.7	De-Morgan's Theorems	9-11	9.18	Standard TTL Characteristics	9-31
9.12	Boolean Expression and Boolean Function	9-12	9.19	Advantages and Disadvantages of TTL	9-32
9.13	Truth Table Formation	9-12	9.19.1	Advantages of TTL	9-32
9.13.1	Examples on Reducing the Boolean Expression	9-12	9.19.2	Disadvantages of TTL	9-32
9.13.2	To Draw a Logic Circuit from Boolean Equation	9-15	9.20	MOS - Logic Family	9-32
9.13.3	To Write a Boolean Expression for a Logic Circuit	9-16	9.21	CMOS Logic	9-32
9.13.4	To Write the Boolean Expression from the Truth Table	9-17	9.21.1	CMOS Inverter	9-32
9.14	Universal Gates	9-18	9.21.2	CMOS NAND Gate	9-33
9.14.1	NAND Gate as Universal Gate	9-18	9.22	CMOS Characteristics	9-34
9.14.2	NOR Gate as a Universal Gate	9-19	9.22.1	Advantages of CMOS	9-35
9.14.3	Solved Examples	9-21	9.22.2	Disadvantages of CMOS	9-35
9.14.4	Logic Circuits	9-22	9.23	Comparison of CMOS and TTL	9-35
			9.24	Multiplexer (Data Selector)	9-36
			9.24.1	Necessity of Multiplexers	9-37

9.24.2 Advantages of Multiplexers 9-37

9.24.3 Applications of a Multiplexer 9-37

9.25 Demultiplexers 9-37

9.25.1 Applications of a demultiplexer 9-38

9.25.2 Comparison of Multiplexer and Demultiplexer 9-38

9.26 Encoders and Decoders 9-38

9.26.1 Encoders 9-38

9.26.2 Decoder 9-39

9.27 Flip-Flops 9-39

9.27.1 Block Diagram of a Flip-Flop 9-39

9.27.2 1-Bit Memory Cell (Basic Bistable Element) 9-40

9.27.3 Basic SR Flip-Flop 9-41

9.28 Edge Triggered Flip Flops 9-42

9.28.1 Positive Edge Triggered S-R Flip Flop 9-42

9.29 Edge Triggered D Flip Flop 9-43

9.29.1 Positive Edge Triggered D Flip Flop 9-44

9.30 Toggle Flip-Flop (T Flip-Flop) 9-44

9.30.1 Positive Edge Triggered FF 9-44

9.30.2 Application of T FF 9-45

9.31 Applications of Flip-Flop 9-45

9.32 Flip Flop as Register 9-45

9.33 Classification of Registers 9-45

9.33.1 Buffer Registers 9-46

9.33.2 Shift Register 9-46

9.33.3 Applications of Shift Registers 9-47

9.34 University Questions and Answers 9-48

• **Review Questions** **9-47**

Module 5

Chapter 10 : Microprocessors and Microcontrollers

10-1 to 10-36

Syllabus : Overview of generic microprocessor, architecture and functional block diagram, Comparison of microprocessor and microcontroller MSP430 architecture, Assembly language programming, C compiler programming, basics of interfacing with external input / output devices (like reading external analog voltages, digital input output). Applications of microcontroller : Temperature measurement, Speed measurement using Proximity Sensor, Piezoelectric Actuator Drive.

10.1 Overview of Generic Microprocessor10-2

10.1.1 Microprocessor Characteristics10-3

10.2 Microprocessor Architecture and Functional Diagram10-4

10.2.1 Register Section10-4

10.2.2 Arithmetic and Logical Unit10-4

10.2.3 Interrupt Control10-4

10.2.4 Timing and Control Unit10-4

10.3 Memory Accessing10-5

10.3.1 Address Bus10-5

10.3.2 Data Bus10-5

10.3.3 Control Bus10-6

10.4 Applications of Microprocessor10-6

10.5 Comparison of Microprocessor and Microcontroller10-6

10.6 MSP 430 Functional Block Diagram and Architecture10-9

10.6.1 Features of MSP43010-9

10.6.2 Functional Block Diagram and Architecture of MSP43010-9

10.7 Assembly Language Programming 10-12



10.7.1	Addressing Modes	10-15
10.7.2	Development Environment	10-17
10.7.3	Programs Based on Simple Digital I/O	10-18
10.8	C Compiler Programming	10-20
10.8.1	Revision of C	10-21
10.8.1.1	Character Set of C	10-21
10.8.1.2	Keywords	10-21
10.8.1.3	Identifiers and data types	10-22
10.8.1.4	Constants and Variables	10-23
10.8.1.5	Escape Sequences	10-23
10.8.1.6	Operators	10-23
10.8.1.7	Precedence and Associativity of Operators	10-28
10.8.2	C Compiler Programming Examples	10-28
10.9	Basics of Interfacing with External Input / Output Devices	10-30
10.9.1	D / A Converters	10-30
10.9.2	A / D Converters	10-31
10.9.3	Interfacing ADC and DAC to MSP430	10-33
10.9.4	Interfacing DAC to MSP430	10-33
10.10	Applications of microcontroller Temperature measurement, Speed Measurement using Proximity Sensor, Piezoelectric Actuator Drive	10-33
10.10.1	Temperature Measurement	10-33
10.10.2	Speed Measurement using Proximity Sensor	10-34
10.10.3	Piezoelectric Actuator Drive	10-34
10.11	University Questions and Answers	10-35
	• Review Questions	10-35

Module 6**Chapter 11 : Motors****11-1 to 11-40**

Syllabus : Review and comparison of DC motors and AC induction motors, Basic principle of speed control of AC induction motor, Basics of BLDC motor, Linear actuator motor, Servo motor; Motor specifications, Suitability of each motor for various industrial applications, Selection and sizing of motors for different applications, Applications for pumps, Conveyors, Machine tools, Microcontroller based speed control for induction motor.

11.1	Introduction	11-3
11.2	Types of DC Machines	11-3
11.2.1	Windings in a DC Machine	11-3
11.2.2	Construction of a DC Motor	11-3
11.2.3	Principle of Operation of a DC Motor	11-4
11.2.4	Direction of Rotation of the Motor	11-4
11.2.5	Torque	11-4
11.2.6	Back EMF and its Significance	11-4
11.3	Voltage Equation of a DC Motor	11-5
11.3.1	Role of Back emf in Controlling Armature Current	11-5
11.3.2	Effect of Load on the DC Motor Operation	11-5
11.4	Types of DC Motors (Classification)	11-6
11.4.1	DC Shunt Motor	11-6
11.4.2	DC Series Motor	11-6
11.5	Torque and Speed Equations	11-7
11.5.1	Torque Equations	11-7
11.5.2	Speed Equations	11-8
11.6	Various Characteristics of a DC Motor	11-8
11.7	Characteristics of DC Shunt Motor	11-8
11.7.1	Torque - Armature Current Characteristics	11-8



11.7.2	Speed-Armature Current Characteristics.....	11-9	11.14.2	Stator Frequency Control or V/f Control	11-20
11.7.3	Speed-Torque Characteristics	11-10	11.15	Industrial Applications of Induction Motors	11-21
11.8	Characteristics of DC Series Motor	11-10	11.15.1	Applications of Squirrel Cage Motors	11-21
11.8.1	Torque - Armature Current Characteristics	11-10	11.15.2	Applications of Slipring Induction Motors	11-21
11.8.2	Speed-Armature Current Characteristics	11-11	11.16	Brushless DC Motor (BLDC Motor)	11-21
11.8.3	Speed-Torque Characteristics	11-11	11.16.1	Operating Principle	11-22
11.8.4	Why Series Motor is Never Started on No Load ?.....	11-12	11.16.2	Advantages of BLDC Motors	11-23
11.9	DC Motor Applications	11-12	11.16.3	Disadvantages of BLDC Motors	11-23
11.9.1	Shunt Motor Applications	11-12	11.16.4	Applications of BLDC Motors	11-23
11.9.2	Series Motor Applications	11-12	11.16.5	Comparison between 3 Phase Induction Motor, BLDC Motor and DC Motor	11-23
11.9.3	Comparison of DC Motors	11-13	11.17	Actuators	11-24
11.10	Three Phase Induction Motor	11-13	11.17.1	Control System	11-24
11.10.1	Advantages of Induction Motors Over DC Motors	11-13	11.17.2	Electric Actuator Motor	11-25
11.10.2	Disadvantages of Induction Motors	11-13	11.18	Sector Induction Motor	11-25
11.10.3	Construction of 3-Phase Induction Motor	11-14	11.18.1	Linear Induction Motor	11-26
11.10.4	Principle of Operation	11-14	11.19	Servomotors	11-27
11.10.5	Direction of RMF	11-15	11.19.1	A.C. Servomotor	11-27
11.11	Types of Induction Motor	11-15	11.19.2	Advantages of AC Servomotors	11-28
11.11.1	Effect of Loading on Induction Motor	11-15	11.19.3	Applications of AC Servomotors	11-29
11.11.2	Synchronous Speed (N_s)	11-15	11.20	DC Servomotors	11-29
11.11.3	Slip s	11-15	11.20.1	Field Controlled DC Servomotor	11-29
11.12	Torque Slip Characteristics of Induction Motor	11-16	11.20.2	Armature Controlled DC Servomotor	11-29
11.13	Comparison of AC and DC Motor	11-18	11.20.3	Applications of DC Servomotor	11-30
11.14	Speed Control of Three Phase Induction Motors	11-18	11.21	Selection of Motors for Different Drives	11-30
11.14.1	Stator Voltage Control	11-19	11.21.1	Cranes, Winches, Hoists	11-31
			11.21.2	Fan or Blower Drives	11-31
			11.21.3	Machine Tools	11-31



11.21.4 Electrical Machines for Pumps11-32	11.24 Microcontroller Based Speed Control of Induction Motor 11-35
11.21.5 Conveyors11-32	11.24.1 Disadvantages of Discrete Drives 11-36
11.22 Motors and their Applications with Reasons11-32	11.24.2 Advantages of Microcontroller Based Drives 11-37
11.23 Types of Loads11-33	11.25 University Questions and Answers 11-38
11.23.1 Continuous Duty11-33	• Review Questions..... 11-37
11.23.2 Short Time Intermittent Duty11-34	
11.23.3 Periodic Intermittent Duty11-35	

□□□