

B. Sc. Physical Sciences with Electronics as one of the Core Disciplines

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 8-2: PHYSICS OF FIELD EFFECT DEVICES

Course Title and Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Physics of Field Effect Devices DSE 8-2	4	3	0	1	

COURSE OBJECTIVES

The objective of this course is to provide a comprehensive understanding of the principles, operation, and characteristics of Field Effect Transistors (FETs), including JFETs, MOSFETs, and advanced structures, while developing the analytical and practical skills needed to model, design, and analyze FET-based circuits in analog and digital systems.

LEARNING OUTCOMES

By the end of the course, students will be able to:

- Explain the operating principles, structural differences, and characteristics of various FET types, including JFETs and MOSFETs.
- Analyze I-V characteristics and apply small-signal models to understand FET behavior in different configurations.
- Design, simulate, and evaluate FET-based amplifier and switching circuits for analog and digital applications.
- Describe advanced FET technologies such as MESFETs and FinFETs, and critically assess challenges related to device scaling and performance.
- Apply knowledge of CMOS technology and nanoelectronic concepts to understand the role of FETs in integrated circuits and emerging electronic systems.

SYLLABUS OF DSE 8-2 **THEORY COMPONENT**

(Hours: 45)

Unit I

(11 Hours)

Junction Field Effect Transistors (JFETs)

Overview of the structure and operational principles of JFETs, emphasizing voltage-controlled conduction via gate-source bias. Analysis of output and transfer characteristics, pinch-off voltage,

and drain current saturation. Study of various JFET biasing techniques and comparison with Bipolar Junction Transistors (BJTs). Applications of JFETs as amplifiers in Common Source (CS), Common Gate (CG), and Common Drain (CD) configurations.

Unit II

(12 Hours)

Metal-Oxide-Semiconductor Field Effect Transistors (MOSFETs)

Detailed study of depletion-mode and enhancement-mode MOSFETs. Construction and operation of n-channel and p-channel MOSFETs. Analysis of MOS capacitors covering accumulation, depletion, and inversion modes, along with corresponding energy band diagrams. Concepts of threshold voltage, effects of work function differences, and interface charges. C-V characteristics, sub-threshold conduction, and MOSFET biasing techniques. Introduction to power MOSFETs, focusing on their high-voltage/current capabilities and switching performance.

Unit III

(11 Hours)

Advanced FETs and Applications

Introduction to MESFETs including their structure, types, and short-channel behavior. Discussion of I-V modeling, field-dependent mobility, and two-region/two-dimensional models. High-frequency characteristics such as current cut-off frequency. Study of GaAs MESFETs. Overview of High Electron Mobility Transistors (HEMTs), including modulation doping and the formation of two-dimensional electron gas (2-DEG) at the AlGaAs/GaAs interface. Advantages and applications of HEMTs.

Unit IV

(11 Hours)

FETs in Integrated Circuits and Nanoelectronics

Exploration of CMOS technology including structure and operation of nMOS, pMOS, and CMOS inverters. Introduction to VLSI design and the impact of channel length scaling. Effects such as body effect, thermal considerations, and reliability concerns. Fundamentals of hetero-epitaxial structures and emerging nanoelectronic components like quantum dots, nanowires, and two-dimensional layered materials.

PRACTICAL COMPONENT: FIELD EFFECT TRANSISTORS

(Hours: 30)

Students should perform at least six experiments from the following list:

1. Analyze the transfer and output characteristics of a Junction Field Effect Transistor (JFET).
2. Investigate the drain and transfer characteristics of an enhancement-mode MOSFET.
3. Examine the operating characteristics of a depletion-mode MOSFET.
4. Implement and evaluate the use of a MOSFET as an amplifier.
5. Study the frequency response of FET amplifiers in Common Source (CS), Common Gate (CG), and Common Drain (CD) configurations.
6. Perform load-line analysis for various FET circuit configurations.
7. Simulate FET-based circuits using SPICE or equivalent circuit simulation tools.
8. Characterize the behavior and switching properties of a CMOS inverter.

9. Determine the threshold voltage and transconductance of a MOSFET.
10. Investigate the switching characteristics of MOSFET devices under different operating conditions.
11. Simulate or measure the I-V characteristics of a High Electron Mobility Transistor (HEMT) and observe the formation of 2DEG.
12. Analyze the high-frequency response and current cut-off behavior of a MESFET using simulation.

REFERENCE

Essential Readings for the Theory Component

- B. G. Streetman, *Solid State Electronic Devices*, PHI.
- S. M. Sze, *Physics of Semiconductor Devices*, John Wiley & Sons.
- Neil Weste & David Harris, *CMOS VLSI Design*, Pearson.
- P. Valizadeh, *Field Effect Transistors: A Comprehensive Overview*, Wiley-Blackwell.
- R. F. Pierret, *Semiconductor Device Fundamentals*, Pearson Education.

Additional Reading for the Theory Component

- Kelly Fotheringham, *MOSFET and GaN FET Application Handbook*, Nexperia UK Ltd.

Essential Readings for the Lab Component

- Stephen A. Campbell, *The Science and Engineering of Microelectronic Fabrication*, Oxford University Press.
- Paul Horowitz and Winfield Hill, *The Art of Electronics*, 3rd Edition, Cambridge University Press.
- B. Somanathan Nair, *Electronic Devices and Applications*, PHI Learning.
- N. N. Bhargava, D. C. Kulshreshtha, S. C. Gupta, *Laboratory Manual for Electronic Devices and Circuits*, Tata McGraw-Hill