

# Coding Theory - Video course

## COURSE OUTLINE

### Course Objective:

To provide an introduction to traditional and modern coding theory. Topics covered include linear block codes, cyclic codes (BCH and RS codes), convolutional codes, turbo codes and low-density parity-check (LDPC) codes.

### Outline:

#### Part I: Basics and Algebraic Codes.

Linear Block Codes: Generator and parity-check matrices, Minimum Distance, Syndrome decoding, Bounds on minimum distance.

Cyclic Codes: Finite fields, Binary BCH codes, RS codes.

#### Part II: Coding in digital communications.

AWGN channel: BPSK modulation, Capacity, Coding gain, ML and MAP decoders, Soft-versus hard-decision decoding.

Convolutional Codes: Encoders, Trellis, Viterbi decoding.

#### Part III: Modern iterative coding.

Turbo codes: Encoders, interleavers, turbo decoder.

Low-density Parity-check Codes: Ensembles of LDPC codes, Message-passing decoders, Threshold phenomenon and density evolution.

## COURSE DETAIL

Lecture No.	Lecture Name	No.of Hours
	<b>Linear Block Codes</b>	7
1	Introduction to Coding Theory, Linear Block Codes, Generator Matrices.	
2	Linear Block Codes, Parity check matrices, Vector space view of codes, Dual codes.	
3	Dual Codes, Self-orthogonal and Self-Dual codes, Examples of dual codes, Relation between parity-check matrix and dual code.	
4	Minimum Distance Decoder, Hamming Distance, Error Correcting Capability of codes, Geometric View of Decoding.	
5	Syndrome Decoder, Relationship between Minimum distance and Parity-Check Matrix.	



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## Electronics & Communication Engineering

### Pre-requisites:

- Undergraduate level courses in probability and random processes, digital communications.

### Additional Reading:

- The theory of error-correcting codes by F. J. MacWilliams and N. J. A. Sloane (North-Holland publishers).
- Algebraic codes for data transmission by Richard Blahut (Cambridge).

### Coordinators:

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6	Construction of Codes with $d=3$ , Hamming Codes, Extending codes, Puncturing Codes.	
7	Shortening codes, Hamming bound, Singleton bound, Gilbert-Varshamov bound, Introduction to finite fields.	
	<b>Finite Fields</b>	3
8	Groups, Order of group elements, Fermat's Little theorem, Finite fields, Polynomials over fields, Polynomial Division.	
9	Polynomial factorization over a field, Irreducible polynomials, Existence and construction of fields of a given size.	
10	Examples of finite field construction, power notation, primitives and primitive polynomials.	
	<b>Codes over Finite Fields (BCH and RS codes)</b>	7
11	BCH codes, Construction of BCH codes for given minimum distance, Vandermonde matrices, BCH bound.	
12	Properties of BCH codes (cyclic), their representation as polynomials, Minimum polynomials.	
13	Minimum polynomials, their construction and properties, their connection with cyclic codes, Generator polynomial of a cyclic code.	
14	Dimension of BCH codes, Examples of BCH codes, Systematic encoding, Syndrome decoding for BCH codes, Error Locators.	
15	Reed-Solomon (RS) Codes, Dimension, Definition of distance, weight in $GF(2^m)$ , Generator polynomial, Minimum distance and binary expansion of RS codes.	
16	Reed-Solomon (RS) Codes: Decoding overview, PGZ decoder for RS codes.	
17	Reed-Solomon codes in practice: erasure decoding, burst erasure correction, some modern decoders.	
	<b>Coding Over AWGN channels</b>	4
18	AWGN channels, Coding gain, Encoding and decoding in AWGN channels.	

19	Bitwise MAP Decoder, Likelihood ratios, LLRs.	
20	ML and Map decoding for Repetition codes, Probability of decoding error, Channel Capacity, Capacity for various schemes, Eb/No, Coding Gain.	
21	Coding gain performances of previously studied codes, Proof of capacity and random codes, Low-Density Parity check (LDPC) codes, Regular LDPC codes, Gallager construction of LDPC codes.	
	<b>LDPC codes</b>	8
22	Socket construction of regular LDPC codes, Tanner Graphs, Neighbourhoods and cycles in graphs.	
23	Gallager A decoding algorithm for LDPC codes and its analysis, LDPC Threshold.	
24	Simulation of Gallager decoding, Neighbourhood view of Gallager A decoding algorithm, Simulation.	
25	Irregular LDPC codes, Node and edge perspective.	
26	Gallager-A decoder on irregular LDPC codes, Degree optimisation to achieve higher thresholds.	
27	Soft-decision Message Passing Decoder for AWGN channels.	
28	Soft-decision Message Passing Decoder for AWGN channels--contd., Density evolution for AWGN channels.	
29	Density evolution for AWGN channels, Summary of LDPC codes.	
	<b>Convolutional codes and turbo codes</b>	6
30	Convolutional codes- Feedforward Convolutional Encoder, Trellis Representation.	
31	Viterbi Decoder for convolutional codes.	
32	Viterbi Decoder (contd.), Recursive convolutional encoders.	
33	Recursive convolutional encoders, Puncturing, Turbo	

	encoders.	
34	Turbo Encoders (contd), Turbo Decoders.	
35	Free distance of convolutional codes, Trellises for block codes, Code concatenation.	
	<b>LDPC/Turbo codes in the wireless standards</b>	<b>5</b>
36	Turbo codes in the WiMax/3GPP standards, permutation polynomial interleavers.	
37	LDPC codes in the WiMax standard, protograph LDPC codes and their properties.	
38	Implementation aspects of turbo codes: MAP decoder and MAXLOGMAP decoder for convolutional codes, design and architecture.	
39	Implementation aspects of LDPC codes: tanh processing versus minsum decoder, design and architecture.	
40	Outlook and the future of the world of error control codes - coding for multi-terminal communication problems.	
	<b>Total</b>	<b>40</b>

**References:**

1. Error Control Coding (2<sup>nd</sup> edition) by Shu Lin and Daniel Costello, Pearson.
2. Modern coding theory by Rudiger Urbanke and Thomas Richardson, Cambridge.