FEC and Line Coding for EFM

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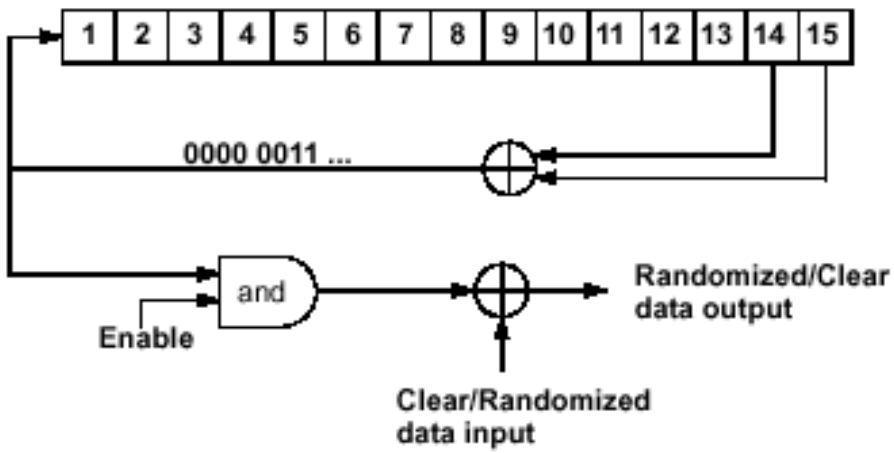
Outline

- Introduction – Line coding and FEC
- Objectives for EFM coding
- Some coding schemes
- Performance
- Summary

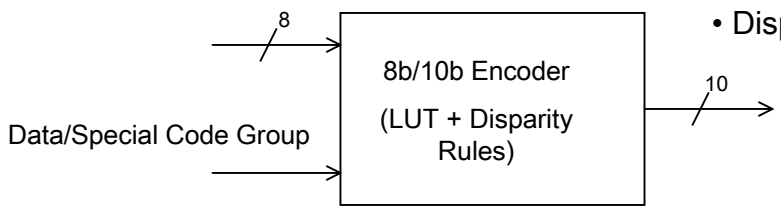
Introduction - Scrambling

- Line Coding Methods
  - Scrambling (Randomization)
    - Ensures randomness of received data stream
    - Advantage: No overhead
    - Disadvantage: Finite probability of “bad” sequences (1s or 0s)



Introduction - 8b/10b coding

- 8B/10B coding
  - High transition density (3-8 transitions per symbol)
  - DC-balanced
  - Special code groups
  - Advantage: No “bad” sequences
  - Disadvantage: High overhead (25%)



8b/10b highlights:

- Input: 1 of 256 data octets and 12 special code groups
- For each input there are 2 possible outputs
- Disparity rules determines which of the 2 outputs to choose

Introduction – Reed-Solomon FEC

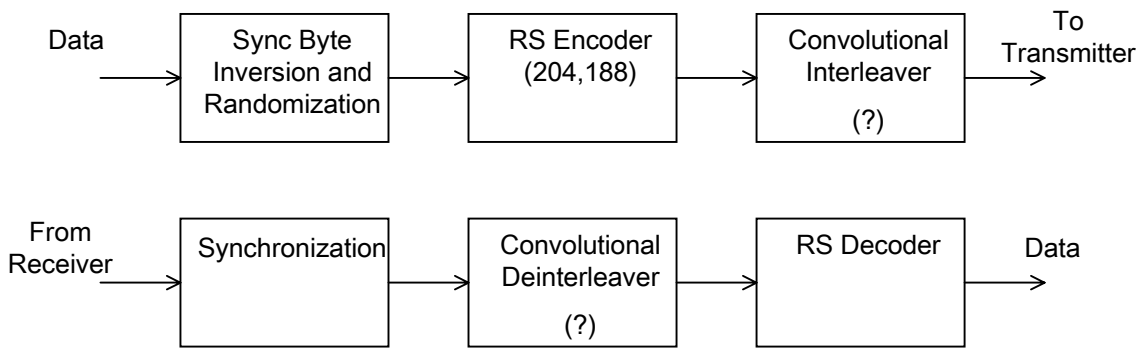
- FEC
  - A shortened, systematic Reed-Solomon code, GF(256)
    - K - information block lengths up to 255 bytes
    - T - error correction capability (1 to 16 bytes)
    - R = 2*T - redundancy bytes (2 to 32 bytes)
    - N – Codeword length
    - If shortened, preceded by (255-N) zero symbols (which are not transmitted)
    - *Code Generator Polynomial:* $g(x) = (x+\mu^0)(x+\mu^1)(x+\mu^2) \ldots (x+\mu^{2T-1})$
    - *Field Generator Polynomial:* $p(x) = x^8+x^4+x^3+x^2+1$

EFM Coding - Objectives

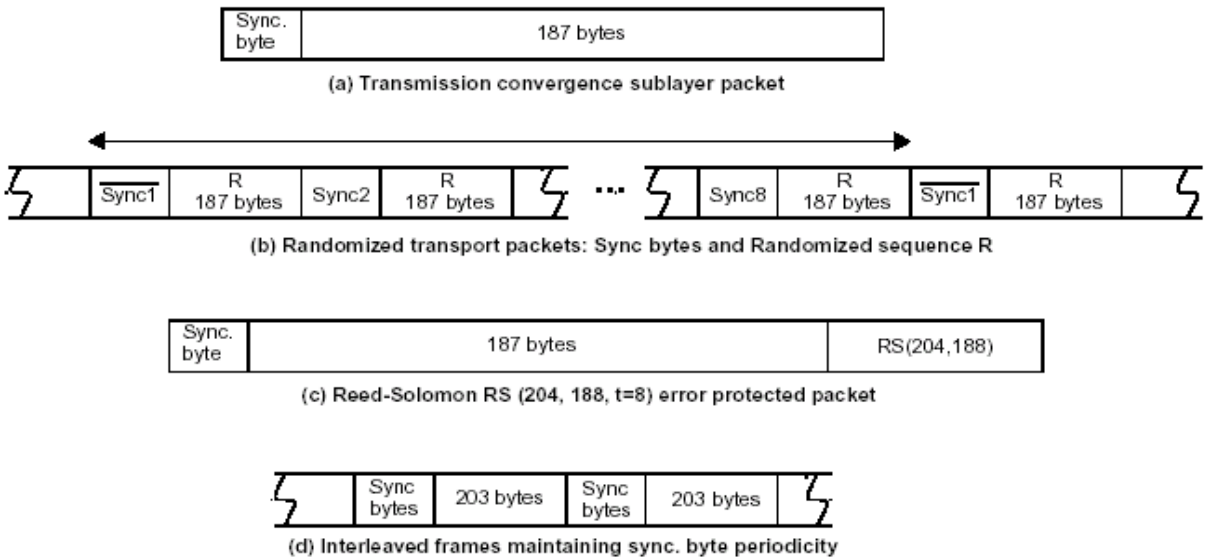
- To improve the transmission characteristics of information to be transferred: Coding Gain
- To ensure sufficient transitions in the PHY bit stream to make clock recovery possible at the receiver
- To give special code-groups for easy recognition bit pattern which assists a receiver in achieving code-group alignment (?)

Coding Schemes – RS and Scrambling

- Reed-Solomon and Scrambling
  - Overhead:
    - FEC – 16 bytes
    - Sync – 1 byte
  - Data rate: 1.25Gbps*0.916=1.146Gbps



Coding Schemes – RS and Scrambling (cont'd)



Sync1 = not randomized complemented sync byte
Sync n = not randomized sync byte, n = 2..8

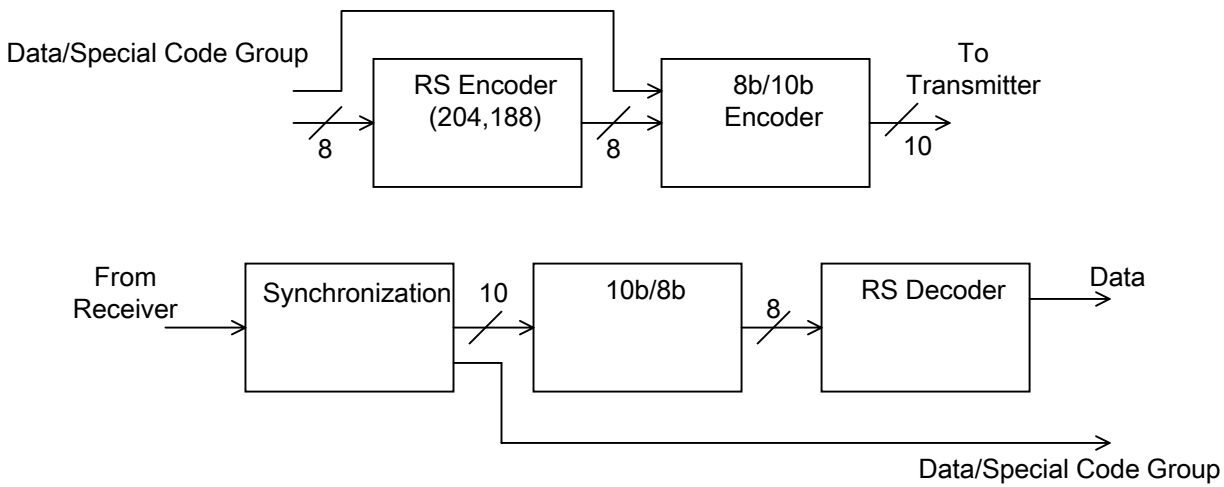
Coding Schemes – RS and Scrambling (cont'd)

- Advantages:
  - Efficient – minimum overhead
  - Good coding gain
- Disadvantages:
  - Probability for large sequences of 0's and 1's
  - High probability of less transitions
  - No special code groups

  - Comment: The FEC overhead bytes can be randomized

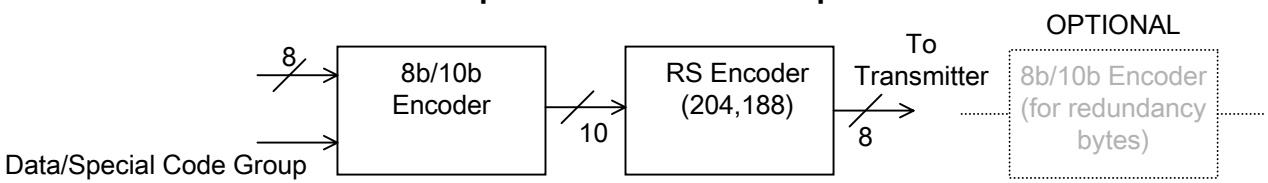
Coding Schemes – Concatenated RS and 8b/10b

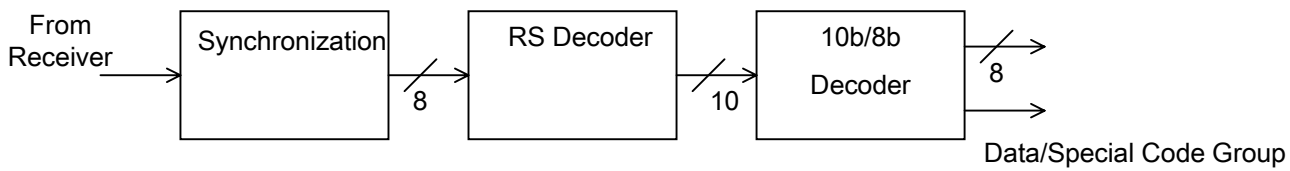
- Concatenated RS and 8B/10B
  - Can't work this way – The special code groups are not FEC protected
  - Problem – There are more than 256 bytes so there is a problem with GF(256) Reed-Solomon codes



Coding Schemes – Concatenated 8b/10b and RS

- Concatenated 8B/10B and RS
  - 188x8=150x10 (+4)
  - Overhead:
    - 8b/10b – 2 bits for each byte
    - FEC – 16 bytes
    - Sync – 10 bits (special code group)
  - Data rate: 1.25Gbps*0.73=917Mbps





Coding Schemes – Concatenated 8b/10b and RS (cont'd)

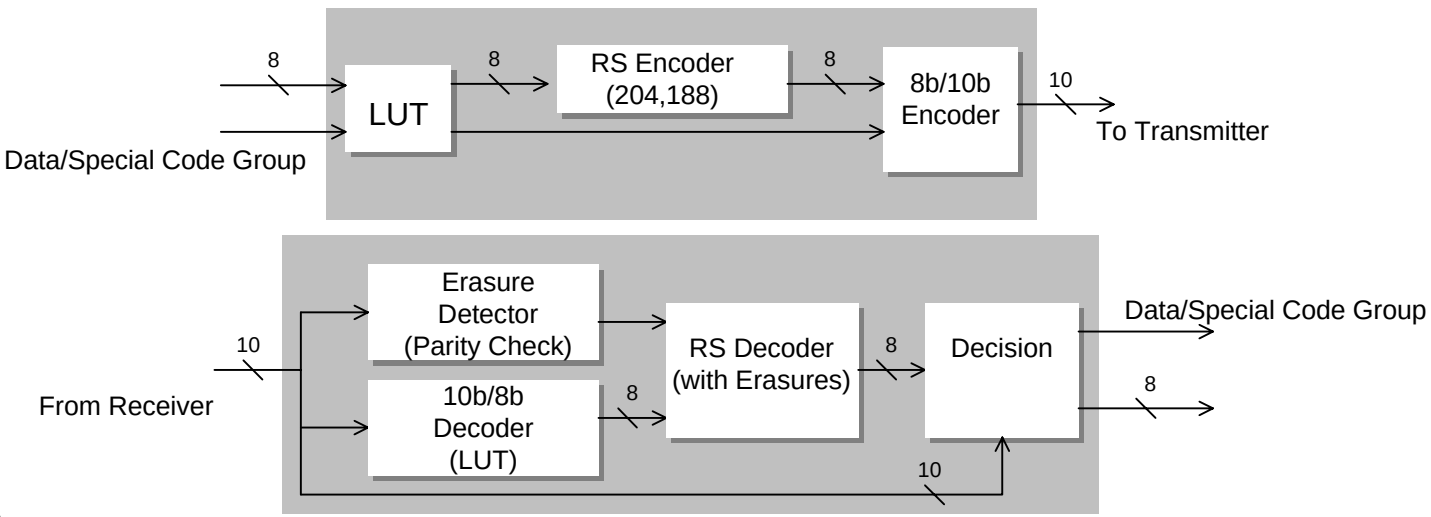
- Meets the 8B/10B requirements
  - High transition density (3-8 transitions per symbol)
  - DC-balanced
  - Special code groups

<u>but not at the overhead bytes</u>

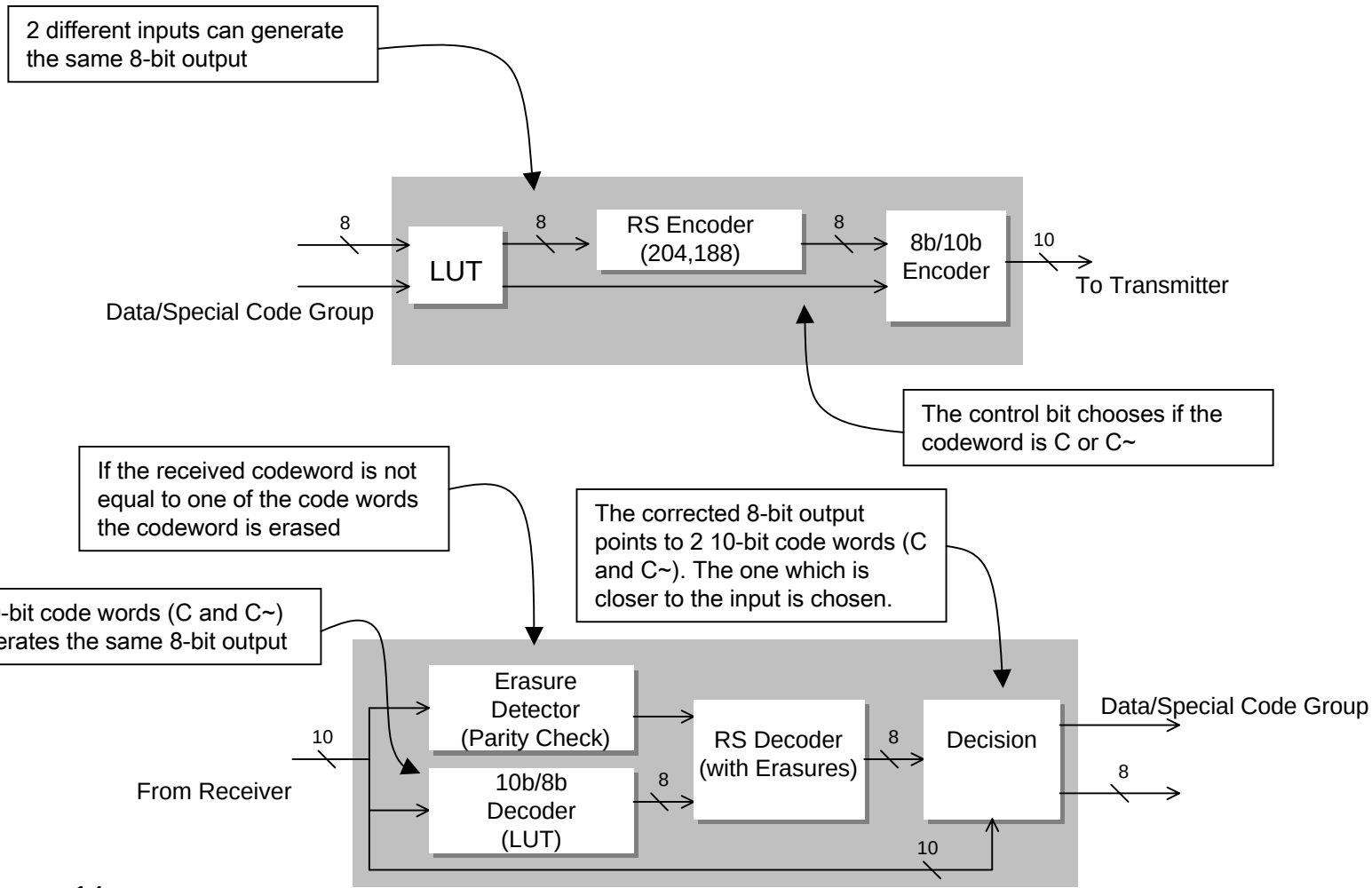
  - 8b/10 encoding of the redundancy bytes (see the optional block)
    - Small performance degradation
- Coding gain is less than the RS and scrambler

Coding Schemes – Concatenated RS and Modified 8b/10b

- Concatenated RS and Modified 8B/10B
  - Overhead:
    - 8b/10b – 2 bits for each byte
    - FEC – 16 bytes
    - Sync – 10 bits (special code group)
  - Data rate: 1.25Gbps*0.73= 917Mbps



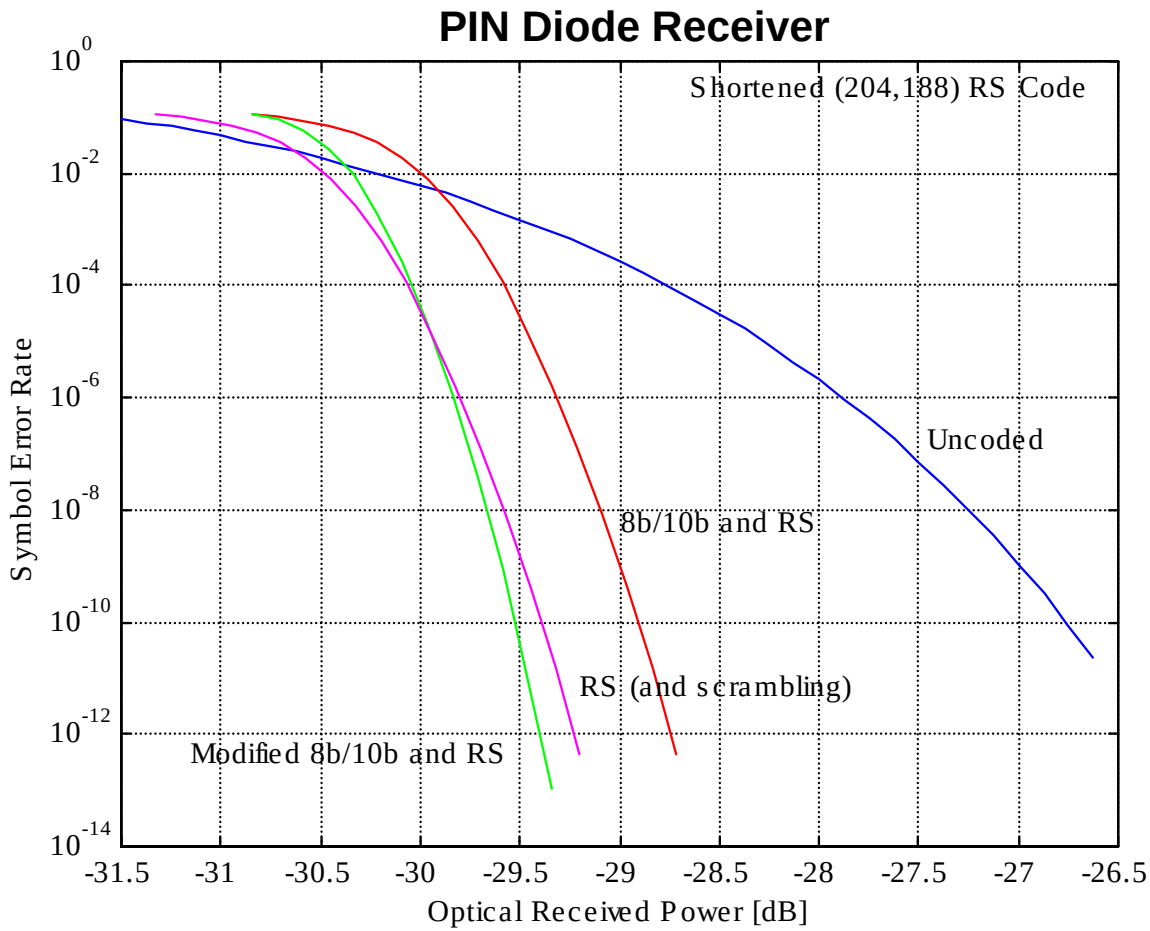
Coding Schemes – Concatenated RS and Modified 8b/10b - Explanation



Coding Schemes – Concatenated RS and Modified 8b/10b (cont'd)

- Modified 8b/10b code
  - Properties:
    - 340 10-bit code words (data and special code groups)
    - Minimum distance between any 2 code words – 2 bits
    - 4 or 6 1's in each codeword
    - At least 4 transitions in each codeword
    - The 340 code words can be divided into 170 complementary pairs (C and C~) (distance=10)
  - 8b/10b is also used for error detection
- Advantages:
  - Improved coding gain because of the erasure algorithm (almost no cost)
  - Meets 8b/10b requirements also for the overhead bytes
- Disadvantages:
  - The DC balance is achieved statistically over larger period

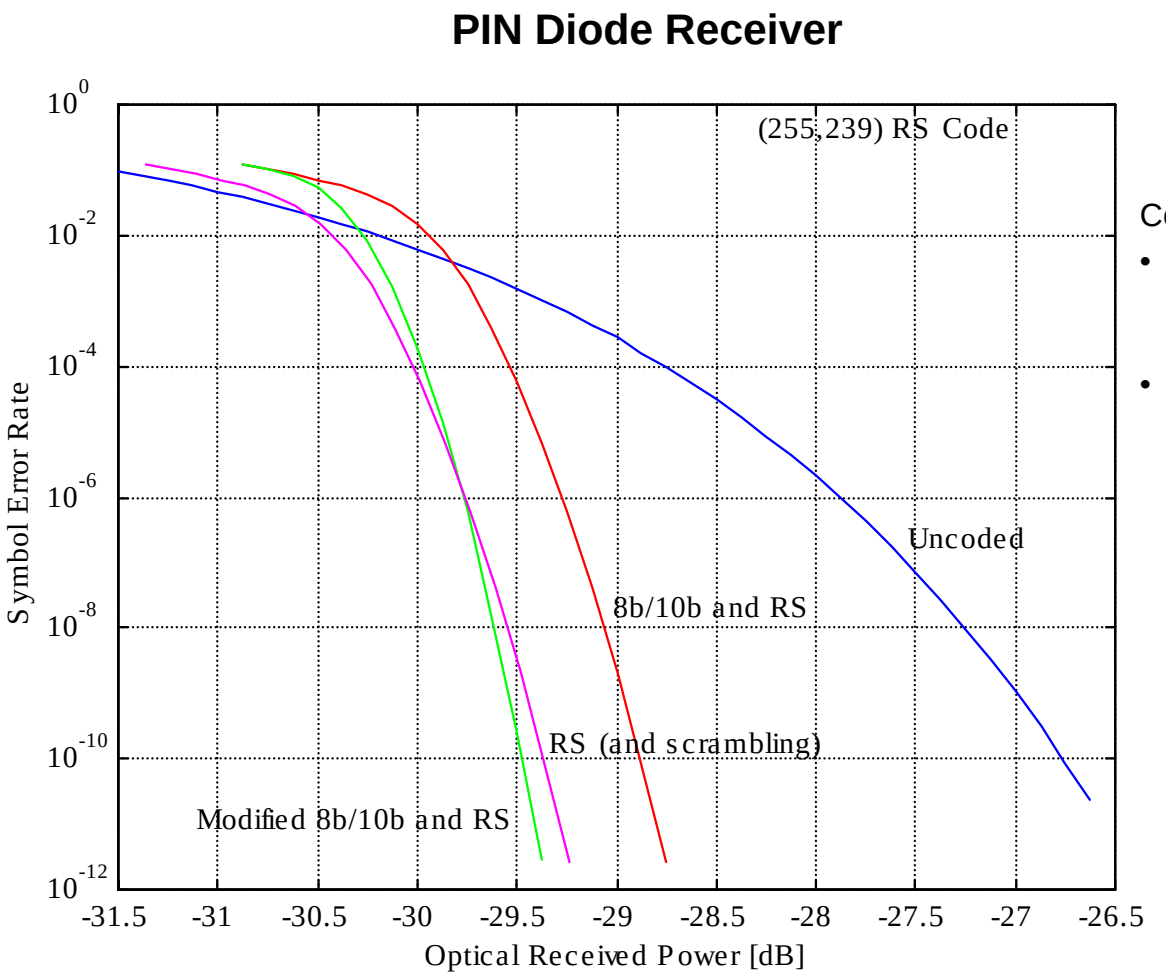
FEC and Line Code Performance



Comments:

- The same data rate is assumed for all the coding schemes
- The optical received power is proportional to Eb/N0

FEC and Line Code Performance



Comments:

- The same data rate is assumed for all the coding schemes
- The optical received power is proportional to Eb/N0

Summary

- 3 coding schemes were presented:
  1. RS and Scrambler – No overhead for line coding
  2. Concatenated 8b/10b and RS – Makes use of the traditional 8b/10b line code which causes 25% overhead
  3. Concatenated RS and Modified 8b/10b – Modification for the traditional 8b/10b code that enables error detection to improve the achieved coding gain

BroadLight

Summary (cont'd)

Coding Scheme	Advantages	Disadvantages	Coding Gain [dB] BER=10^{-10}
RS Only (and scrambling)	• Efficient	• Number of transitions not guaranteed • Large sequences of 1's and 0's • No special code groups	2.45
Concatenated 8b/10b and RS	• Efficient (but less than the others) • Supports special code groups	• Transitions density not guaranteed in FEC overhead bytes	2
Concatenated RS and Modified 8b/10b	• Efficient • Supports special code groups • Transitions density guaranteed	• DC balance guaranteed over larger period	2.55

Pair #	Ci	# of 1s	# of transitions	Ci~	# of 1s	# of transitions
1	0 0 0 0 0 1 0 1 0 1 1	4	5	1 1 1 1 1 0 1 0 1 0 0	6	5
2	0 0 0 0 0 1 0 1 1 0 1	4	5	1 1 1 1 1 0 1 0 0 1 0	6	5
3	0 0 0 0 0 1 0 1 1 1 0	4	4	1 1 1 1 1 0 1 0 0 0 1	6	4
4	0 0 0 0 0 1 1 0 1 0 1	4	5	1 1 1 1 1 0 0 1 0 1 0	6	5
5	0 0 0 0 0 1 1 0 1 1 0	4	4	1 1 1 1 1 0 0 1 0 0 1	6	4
6	0 0 0 0 0 1 1 1 0 1 0	4	4	1 1 1 1 1 0 0 0 1 0 1	6	4
7	0 0 0 0 1 0 0 1 0 1 1	4	5	1 1 1 1 0 1 1 0 1 0 0	6	5
8	0 0 0 0 1 0 0 1 1 0 1	4	5	1 1 1 1 0 1 1 0 0 1 0	6	5
9	0 0 0 0 1 0 0 1 1 1 0	4	4	1 1 1 1 0 1 1 0 0 0 1	6	4
10	0 0 0 0 1 0 1 0 0 1 1	4	5	1 1 1 1 0 1 0 1 1 0 0	6	5
11	0 0 0 0 1 0 1 0 1 0 1	4	7	1 1 1 1 0 1 0 1 0 1 0	6	7
12	0 0 0 0 1 0 1 0 1 1 0	4	6	1 1 1 1 0 1 0 1 0 0 1	6	6
13	0 0 0 0 1 0 1 1 0 0 1	4	5	1 1 1 1 0 1 0 0 1 1 0	6	5
14	0 0 0 0 1 0 1 1 0 1 0	4	6	1 1 1 1 0 1 0 0 1 0 1	6	6
15	0 0 0 0 1 0 1 1 1 0 0	4	4	1 1 1 1 0 1 0 0 0 1 1	6	4
16	0 0 0 0 1 1 0 0 1 0 1	4	5	1 1 1 1 0 0 1 1 0 1 0	6	5
17	0 0 0 0 1 1 0 0 1 1 0	4	4	1 1 1 1 0 0 1 1 0 0 1	6	4
18	0 0 0 0 1 1 0 1 0 0 1	4	5	1 1 1 1 0 0 1 0 1 1 0	6	5
19	0 0 0 0 1 1 0 1 0 1 0	4	6	1 1 1 1 0 0 1 0 1 0 1	6	6
20	0 0 0 0 1 1 0 1 1 0 0	4	4	1 1 1 1 0 0 1 0 0 1 1	6	4
21	0 0 0 0 1 1 1 0 0 1 0	4	4	1 1 1 1 0 0 0 1 1 0 1	6	4
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23	0 0 1 0 0 0 1 0 1 1 1	4	5	1 1 0 1 1 1 0 1 0 0 0	6	5
24	0 0 1 0 0 0 1 1 0 1 1	4	5	1 1 0 1 1 1 0 0 1 0 0	6	5
25	0 0 1 0 0 0 1 1 1 0 0	4	4	1 1 0 1 1 1 0 0 0 1 0	6	4
26	0 0 1 0 0 1 0 0 1 1 1	4	5	1 1 0 1 1 0 1 1 0 0 0	6	5
27	0 0 1 0 0 1 0 1 0 1 1	4	7	1 1 0 1 1 0 1 0 1 0 0	6	7
28	0 0 1 0 0 1 0 1 1 0 0	4	6	1 1 0 1 1 0 1 0 0 1 0	6	6
29	0 0 1 0 0 1 1 0 0 1 1	4	5	1 1 0 1 1 0 0 1 1 0 0	6	5
30	0 0 1 0 0 1 1 0 1 0 0	4	6	1 1 0 1 1 0 0 1 0 1 0	6	6
31	0 0 1 0 0 1 1 1 0 0 0	4	4	1 1 0 1 1 0 0 0 1 1 0	6	4
32	0 0 1 0 1 0 0 0 1 1 1	4	5	1 1 0 1 0 1 1 1 0 0 0	6	5
33	0 0 1 0 1 0 0 1 0 1 1	4	7	1 1 0 1 0 1 1 0 1 0 0	6	7
34	0 0 1 0 1 0 0 1 1 0 0	4	6	1 1 0 1 0 1 1 0 0 1 0	6	6
35	0 0 1 0 1 0 1 0 0 1 1	4	7	1 1 0 1 0 1 0 1 1 0 0	6	7
36	0 0 1 0 1 0 1 0 1 0 0	4	8	1 1 0 1 0 1 0 1 0 1 0	6	8
37	0 0 1 0 1 0 1 1 0 0 0	4	6	1 1 0 1 0 1 0 0 1 1 0	6	6
38	0 0 1 0 1 0 1 1 1 1 1	6	5	1 1 0 1 0 1 0 0 0 0 0	4	5
39	0 0 1 0 1 1 0 0 0 1 1	4	5	1 1 0 1 0 0 1 1 1 1 0	6	5
40	0 0 1 0 1 1 0 0 1 0 0	4	6	1 1 0 1 0 0 1 1 0 1 0	6	6
41	0 0 1 0 1 1 0 1 0 0 0	4	6	1 1 0 1 0 0 1 0 1 1 0	6	6
42	0 0 1 0 1 1 0 1 1 1 1	6	5	1 1 0 1 0 0 1 0 0 0 0	4	5
43	0 0 1 0 1 1 1 0 0 0 0	4	4	1 1 0 1 0 0 0 1 1 1 0	6	4
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72	0 1 0 0 0 1 0 0 1 1 1	4	5	1 0 1 1 1 0 1 1 0 0 0	6	5
73	0 1 0 0 0 1 0 1 0 1 1	4	7	1 0 1 1 1 0 1 0 1 0 0	6	7
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Pair #	Ci	# of 1s	# of transitions	Ci~	# of 1s	# of transitions
86	0 1 0 0 1 1 0 0 1 0 1	4	6	1 0 1 1 0 0 1 1 0 1 0	6	6
87	0 1 0 0 1 1 0 1 0 0 1	4	6	1 0 1 1 0 0 1 0 1 1 0	6	6
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92	0 1 0 0 1 1 1 1 1 1 0	6	4	1 0 1 1 0 0 0 0 0 1 1	4	4
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94	0 1 0 1 0 0 0 0 1 0 1	4	7	1 0 1 0 1 1 1 1 0 1 0	6	7
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96	0 1 0 1 0 0 0 1 0 0 1	4	7	1 0 1 0 1 1 1 0 1 1 0	6	7
97	0 1 0 1 0 0 0 1 0 1 0	4	8	1 0 1 0 1 1 1 0 1 0 1	6	8
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109	0 1 0 1 1 0 0 0 1 0 0	4	6	1 0 1 0 0 0 1 1 1 0 1	6	6
110	0 1 0 1 1 0 0 1 0 0 0	4	6	1 0 1 0 0 0 1 1 0 1 1	6	6
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116	0 1 0 1 1 1 0 0 0 0 0	4	4	1 0 1 0 0 0 1 1 1 1 0	6	4
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120	0 1 0 1 1 1 1 0 0 1 0	6	5	1 0 1 0 0 0 0 1 1 0 1	4	5
121	0 1 0 1 1 1 1 0 1 0 1	6	6	1 0 1 0 0 0 0 1 0 1 0	4	6
122	0 1 0 1 1 1 1 1 0 0 0	6	4	1 0 1 0 0 0 0 0 1 1 1	4	4
123	0 1 1 0 0 0 0 1 0 1 1	4	5	1 0 0 1 1 1 1 1 0 1 0	6	5
124	0 1 1 0 0 0 0 1 1 1 0	4	4	1 0 0 1 1 1 1 1 0 0 1	6	4
125	0 1 1 0 0 0 1 0 0 1 1	4	5	1 0 0 1 1 1 1 0 1 1 0	6	5
126	0 1 1 0 0 0 1 0 1 0 1	4	6	1 0 0 1 1 1 1 0 1 0 1	6	6
127	0 1 1 0 0 0 1 1 0 0 0	4	4	1 0 0 1 1 1 1 0 0 1 1	6	4
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131	0 1 1 0 0 1 0 1 1 1 1	6	5	1 0 0 1 1 0 1 0 0 0 0	4	5
132	0 1 1 0 0 1 1 0 0 0 0	4	4	1 0 0 1 1 0 0 1 1 1 0	6	4
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137	0 1 1 0 1 0 0 0 1 0 0	4	6	1 0 0 1 0 1 1 1 0 1 0	6	6
138	0 1 1 0 1 0 0 1 0 1 0	4	6	1 0 0 1 0 1 1 0 1 0 1	6	6
139	0 1 1 0 1 0 0 1 1 1 1	6	5	1 0 0 1 0 1 1 0 0 0 0	4	5
140	0 1 1 0 1 0 1 0 0 0 0	4	6	1 0 0 1 0 1 1 0 1 1 1	6	6
141	0 1 1 0 1 0 1 0 1 1 1	6	7	1 0 0 1 0 1 1 0 1 0 0	4	7
142	0 1 1 0 1 0 1 1 0 0 1	6	7	1 0 0 1 0 1 1 0 0 1 0	4	7
143	0 1 1 0 1 0 1 1 1 1 0	6	6	1 0 0 1 0 1 1 0 0 0 1	4	6
144	0 1 1 0 1 1 0 0 0 0 0	4	4	1 0 0 1 0 1 0 1 1 1 1	6	4
145	0 1 1 0 1 1 0 0 1 1 1	6	5	1 0 0 1 0 1 0 0 1 1 0	4	5
146	0 1 1 0 1 1 0 1 0 1 0	6	7	1 0 0 1 0 1 0 0 1 0 1	4	7
147	0 1 1 0 1 1 0 1 1 1 0	6	6	1 0 0 1 0 1 0 0 1 0 1	4	6
148	0 1 1 0 1 1 1 0 0 1 1	6	5	1 0 0 1 0 1 0 0 0 1 1	4	5
149	0 1 1 0 1 1 1 0 1 1 0	6	6	1 0 0 1 0 0 0 1 0 1 1	4	6
150	0 1 1 0 1 1 1 1 0 0 0	6	4	1 0 0 1 0 0 0 0 1 1 1	4	4
151	0 1 1 1 0 0 0 0 1 0 1	4	4	1 0 0 0 1 1 1 1 0 1 0	6	4
152	0 1 1 1 0 0 0 1 0 0 0	4	4	1 0 0 0 1 1 1 0 1 1 0	6	4
153	0 1 1 1 0 0 1 0 0 0 0	4	4	1 0 0 0 1 1 0 1 1 1 0	6	4
154	0 1 1 1 0 0 1 0 1 1 1	6	5	1 0 0 0 1 1 0 1 0 0 0	4	5
155	0 1 1 1 0 0 1 1 0 1 0	6	5	1 0 0 0 1 1 0 0 1 0 1	4	5
156	0 1 1 1 0 0 1 1 1 1 0	6	4	1 0 0 0 1 1 0 0 0 1 1	4	4
157	0 1 1 1 0 1 0 0 0 0 0	4	4	1 0 0 0 1 0 1 1 1 1 0	6	4
158	0 1 1 1 0 1 0 0 1 1 1	6	5	1 0 0 0 1 0 1 1 1 0 0	4	5
159	0 1 1 1 0 1 0 1 0 1 0	6	7	1 0 0 0 1 0 1 1 0 1 0	4	7
160	0 1 1 1 0 1 0 1 1 1 0	6	6	1 0 0 0 1 0 1 1 0 0 1	4	6
161	0 1 1 1 0 1 1 0 0 1 0	6	5	1 0 0 0 1 0 1 1 0 1 1	4	5
162	0 1 1 1 0 1 1 0 1 1 0	6	6	1 0 0 0 1 0 0 1 0 1 1	4	6
163	0 1 1 1 0 1 1 1 1 0 0	6	4	1 0 0 0 1 0 0 0 1 1 1	4	4
164	0 1 1 1 1 0 0 1 0 1 0	6	5	1 0 0 0 0 1 1 1 0 1 0	4	5
165	0 1 1 1 1 0 0 1 1 1 0	6	4	1 0 0 0 0 1 1 1 0 0 1	4	4
166	0 1 1 1 1 0 1 0 0 1 0	6	5	1 0 0 0 0 1 1 0 1 1 0	4	5
167	0 1 1 1 1 0 1 0 1 0 0	6	6	1 0 0 0 0 1 1 0 1 0 1	4	6
168	0 1 1 1 1 0 1 1 0 0 0	6	4	1 0 0 0 0 1 1 0 0 1 1	4	4
169	0 1 1 1 1 1 0 0 1 0 0	6	4	1 0 0 0 0 0 1 1 1 0 1	4	4
170	0 1 1 1 1 1 0 1 0 0 0	6	4	1 0 0 0 0 0 1 0 1 1 1	4	4