Error Correcting Codes for High Altitude Balloons

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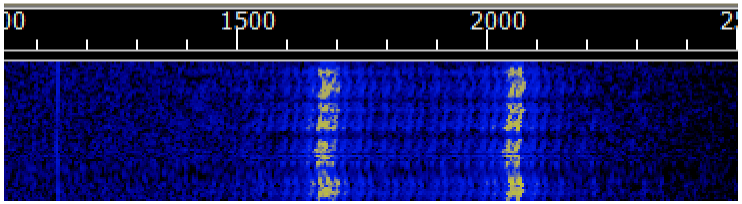
Why Error Correction Codes are Needed

- Reducing transmitted power
- Maintain reliable communication in unfavourable conditions
  - Bursts of interference
  - Fading signal
  - Low SNR
- Increase throughput



Some Error Correcting Codes

- Block
  - BCH (1960)
  - Reed Solomon (1960) — CDs/DVDs, DVB-T
  - LDPC (1963, 1996) — DVB-S2
- Convolutional
  - Viterbi decoded (1967) — DVB-T, deep space
  - BCJR decoded (1974)
  - Turbo (1993) — LTE

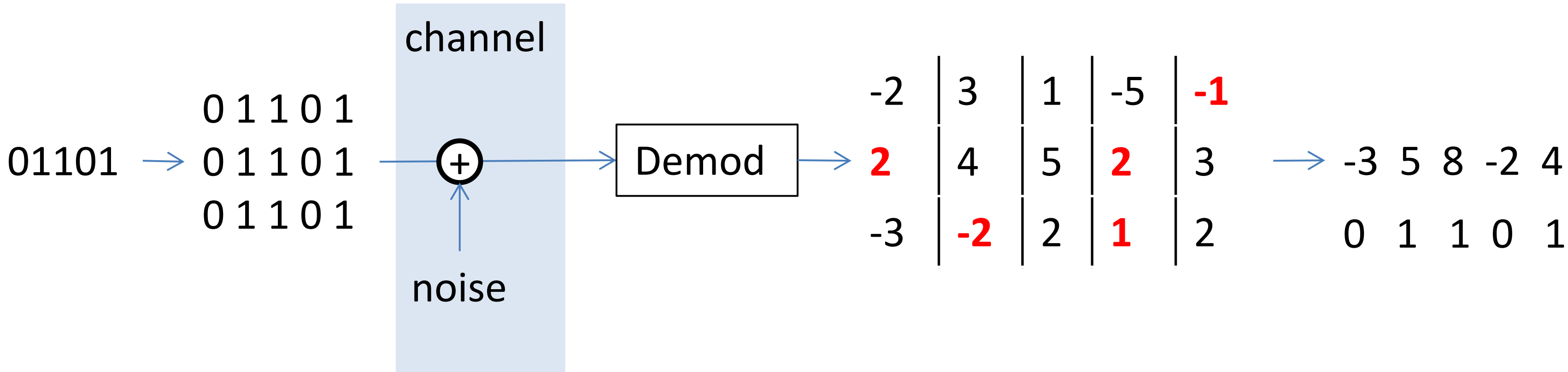
A Very Basic Code

01101 → 000 111 111 000 111 → ⊕ → 0**1**0 11**0** 111 0**11** **0**11 → 011**1**1

noise

- Repetition code
- 1/3 rate code
- Encoder: simple
- Decoder: simple
- Performance: bad

An Improvement

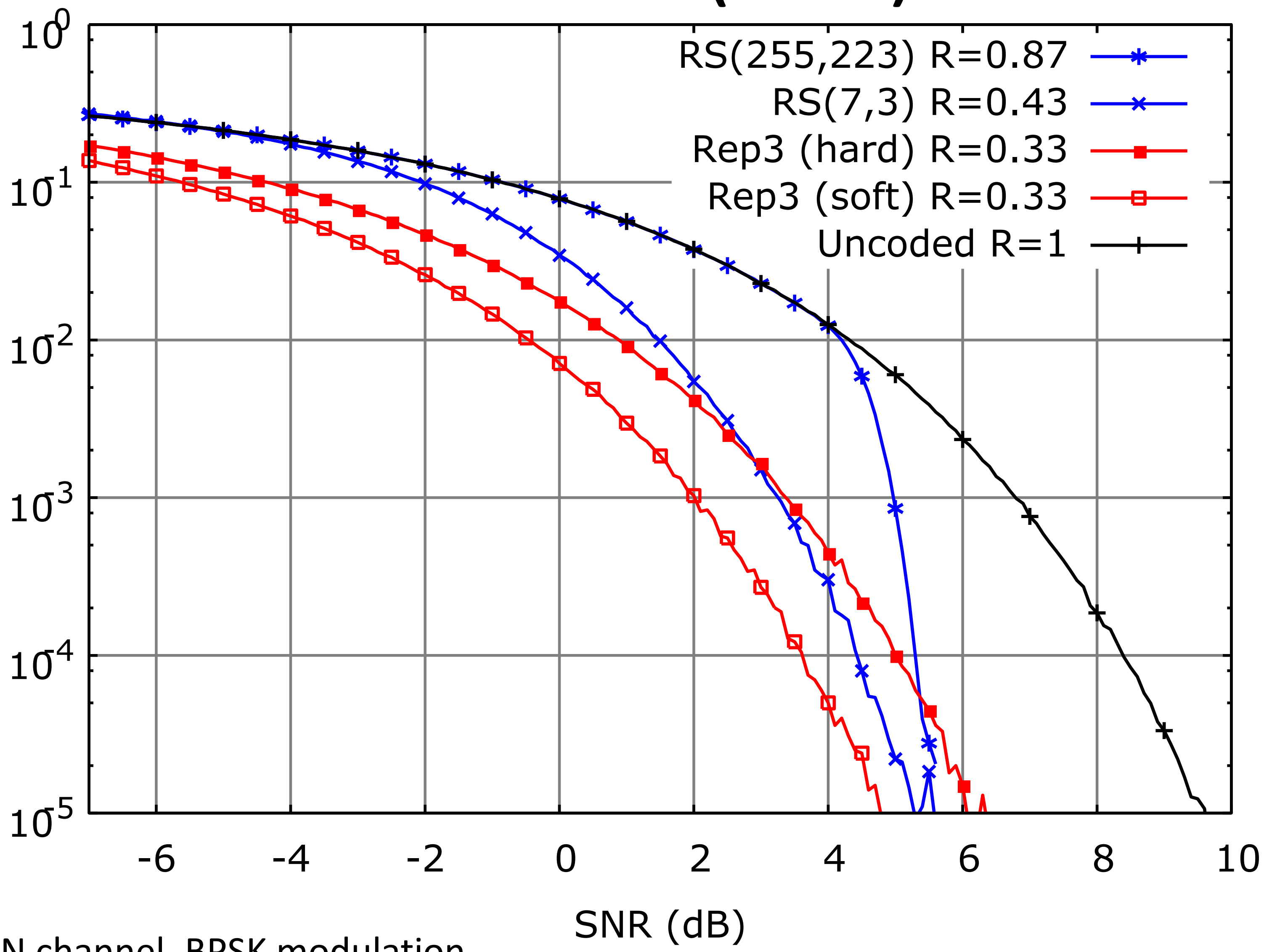


- Soft information conveys probabilities for each bit
- Usually expressed in the log domain, numbers have much smaller dynamic range
  - Known as Log Likelihood Ratio (LLR)

Reed Solomon (RS) Code

- Developed in 1960s
- Block Code
- Non-binary
- Adds *t* parity symbols, can correct up to *t/2* symbol errors
- Examples
  - RS(7,3) – R=0.43, symbol = 3 bits, 4 parity symbols
  - RS(255,223) – R=0.87, symbol = 8 bits, 32 parity symbols

Bit Error Rate (BER) Plot

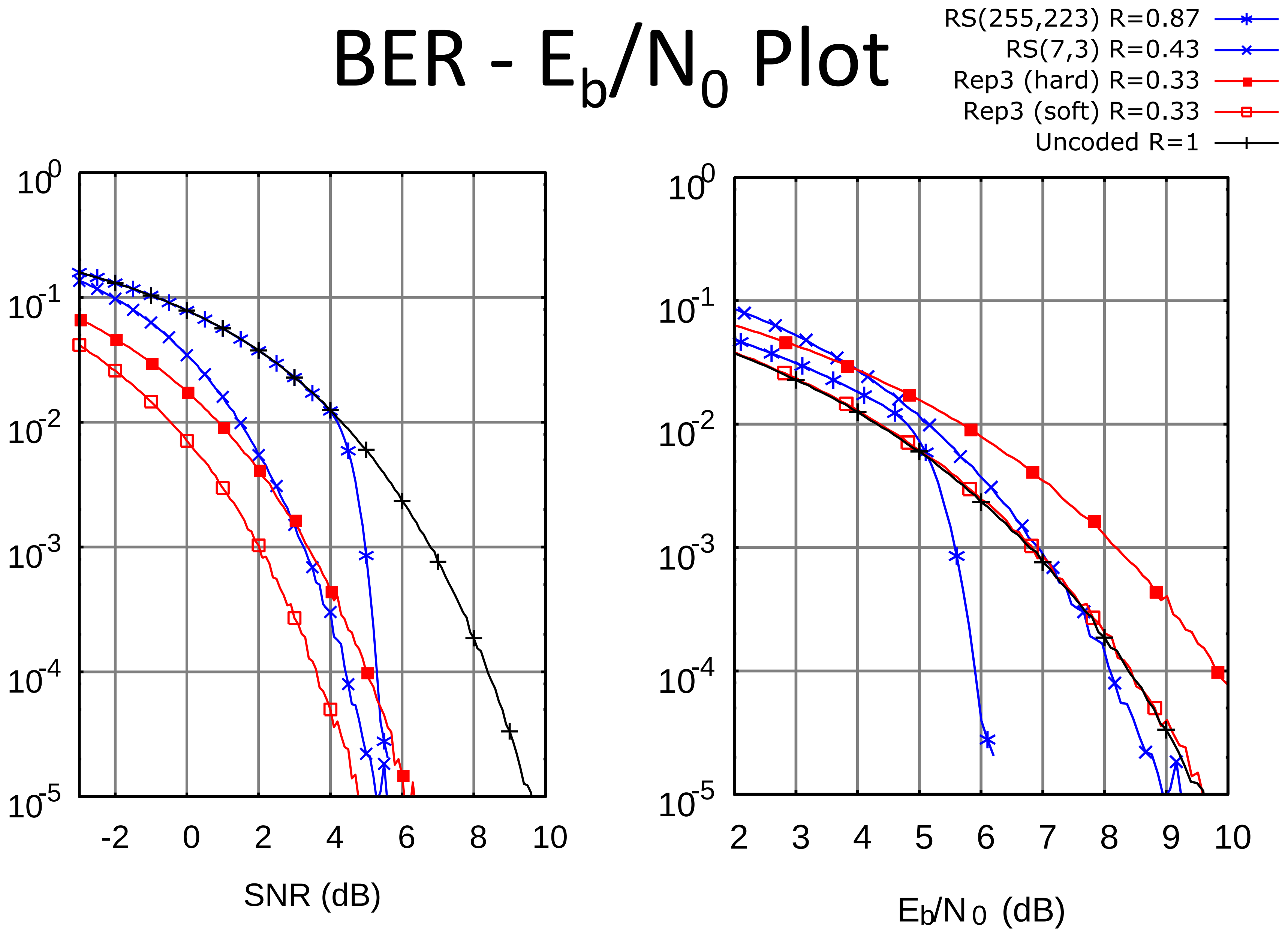


- AWGN channel, BPSK modulation

E_b/N_0 vs. SNR

- SNR provides unfair comparison between codes of different rates
- E_b/N_0 – 'SNR per data bit'
  - $E_b/N_0 = \text{SNR} - 10\log_{10}(R)$
  - Two schemes at the same E_b/N_0 use the same energy to transmit a sequence
  - Takes into account extra bits that need to be sent
    - Either extra bits take more bandwidth
    - Extra bits are added on at the end – take more time

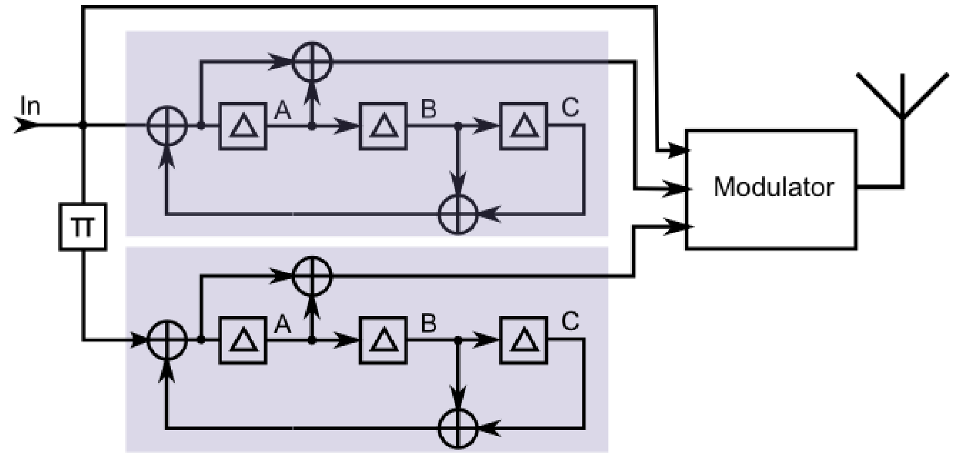
BER - E_b/N_0 Plot

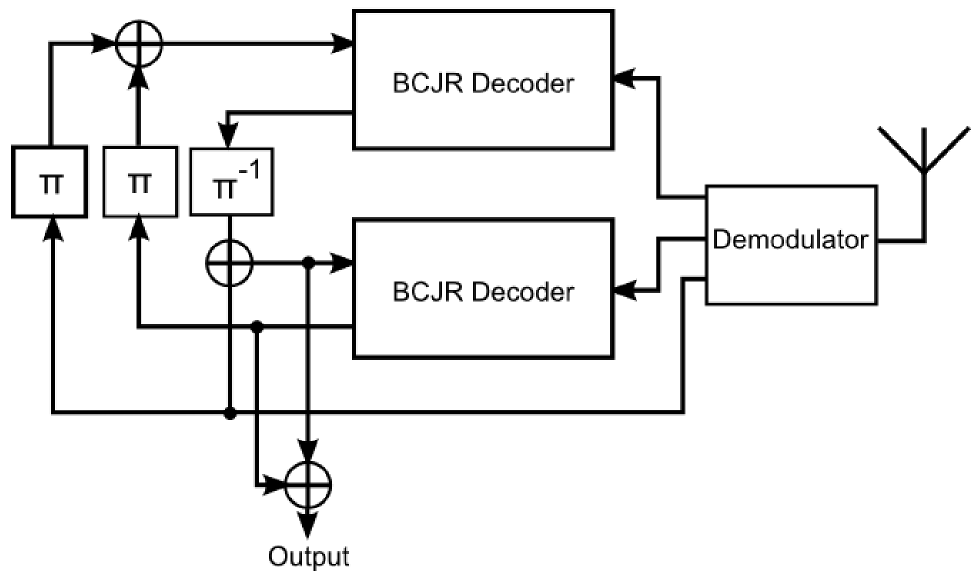


- AWGN channel, BPSK modulation

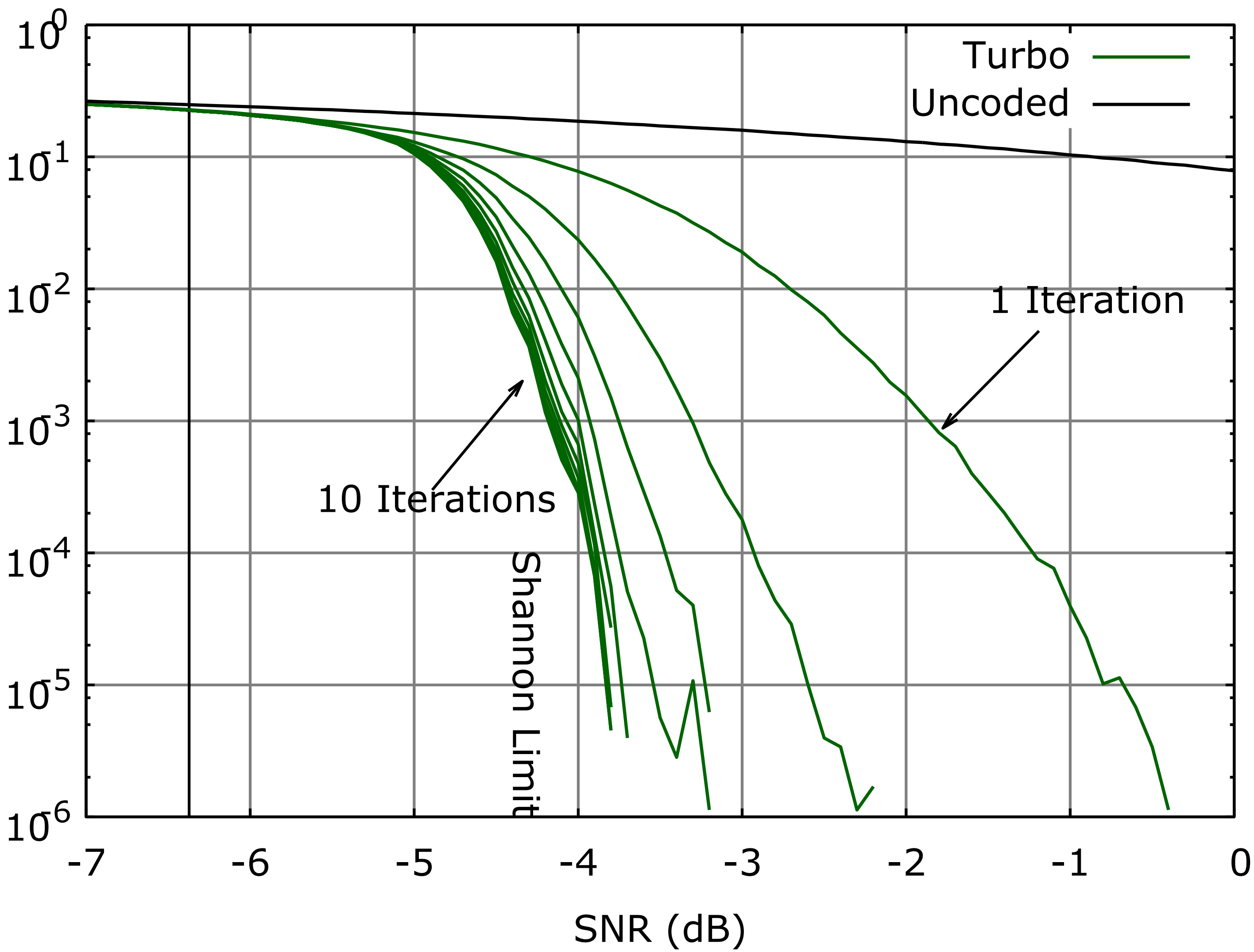
Turbo Code

- Combines two convolutional codes
- 1/3 rate code (min)
  - Puncture the output to get desired rate
- Uses soft information
- Uses iterative decoding



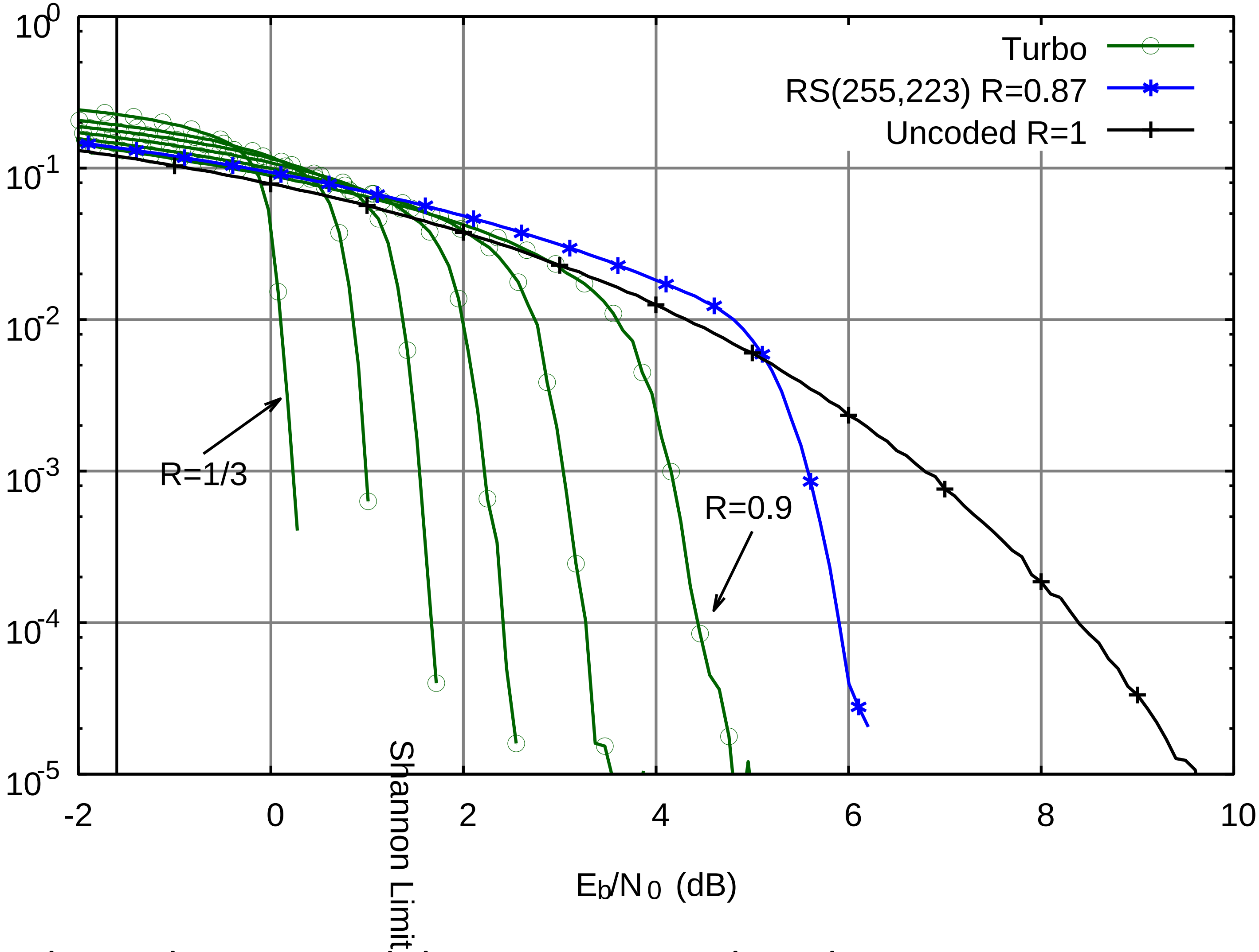


BER for Turbo Code, Varying Iterations



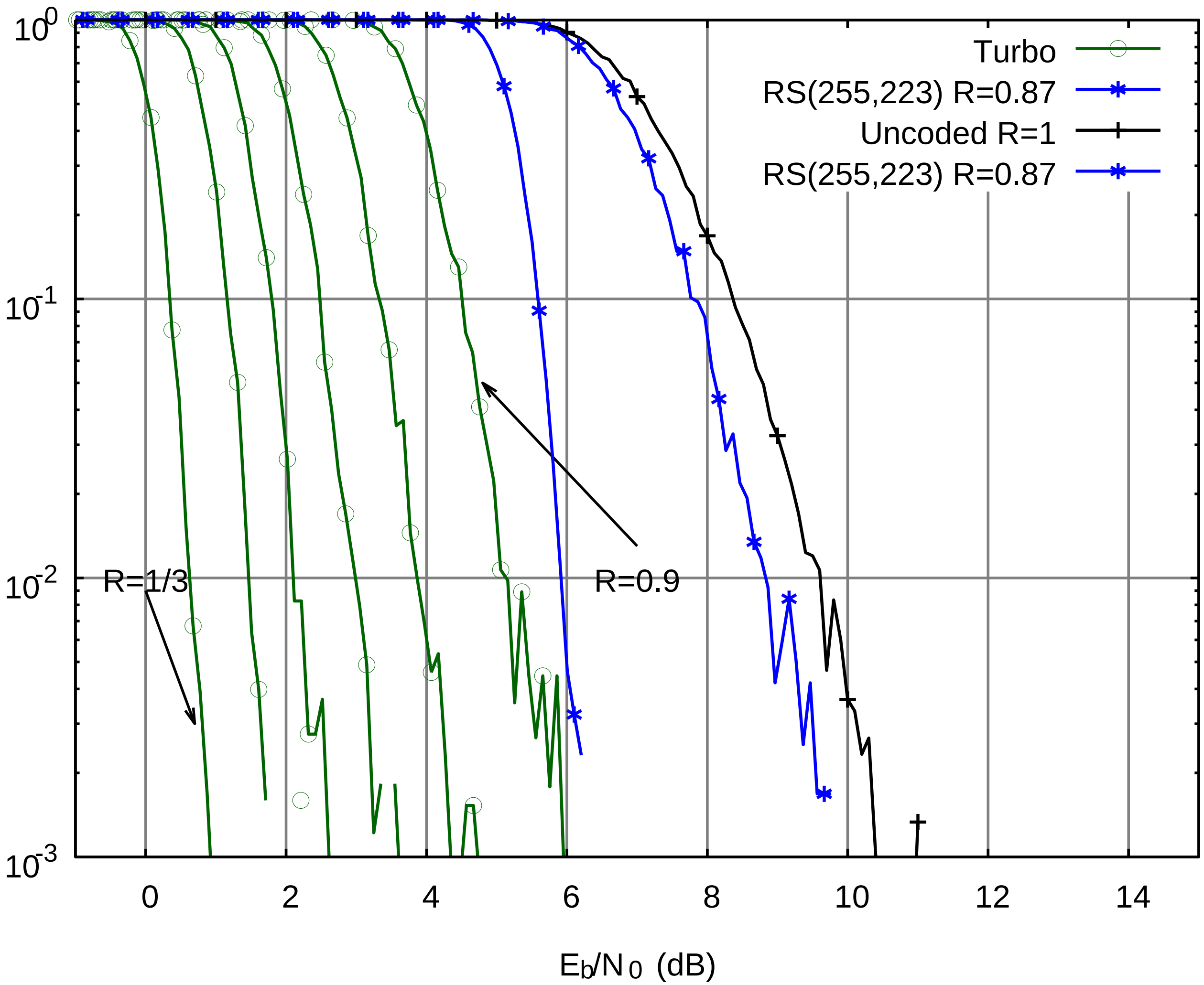
- AWGN channel, BPSK modulation, message length = 6144

BER - E_b/N_0 Plot



- AWGN channel, BPSK modulation, message length = 6144

FER

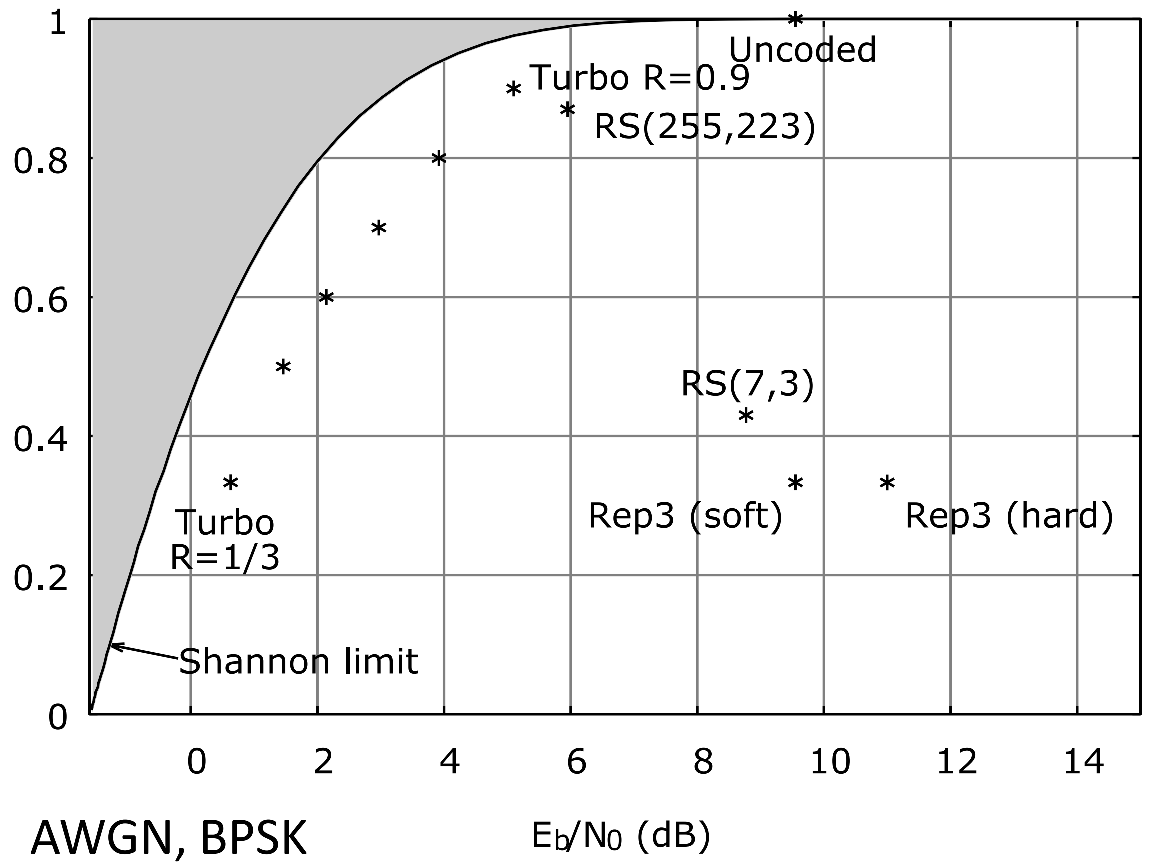


- AWGN, BPSK, message length = 992 (turbo & RS(7,3)); 1784 (RS(255,223))

Capacity

- Theoretical max throughput for given SNR
- Graph shows capacity limit for FER = 10^{-2}

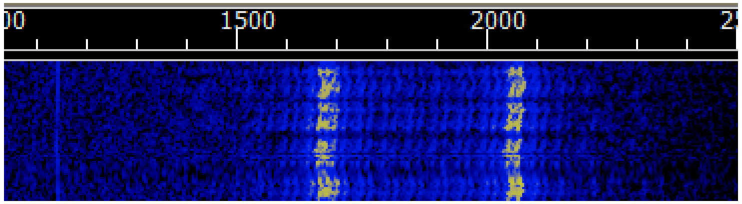
- $C = B \cdot log_2\left(\frac{S}{N} + 1\right)$

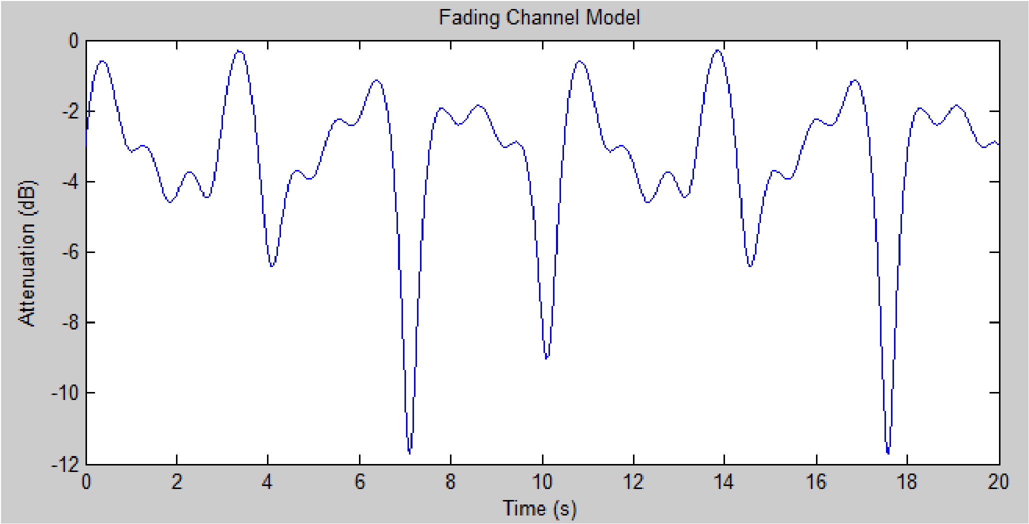


- AWGN, BPSK

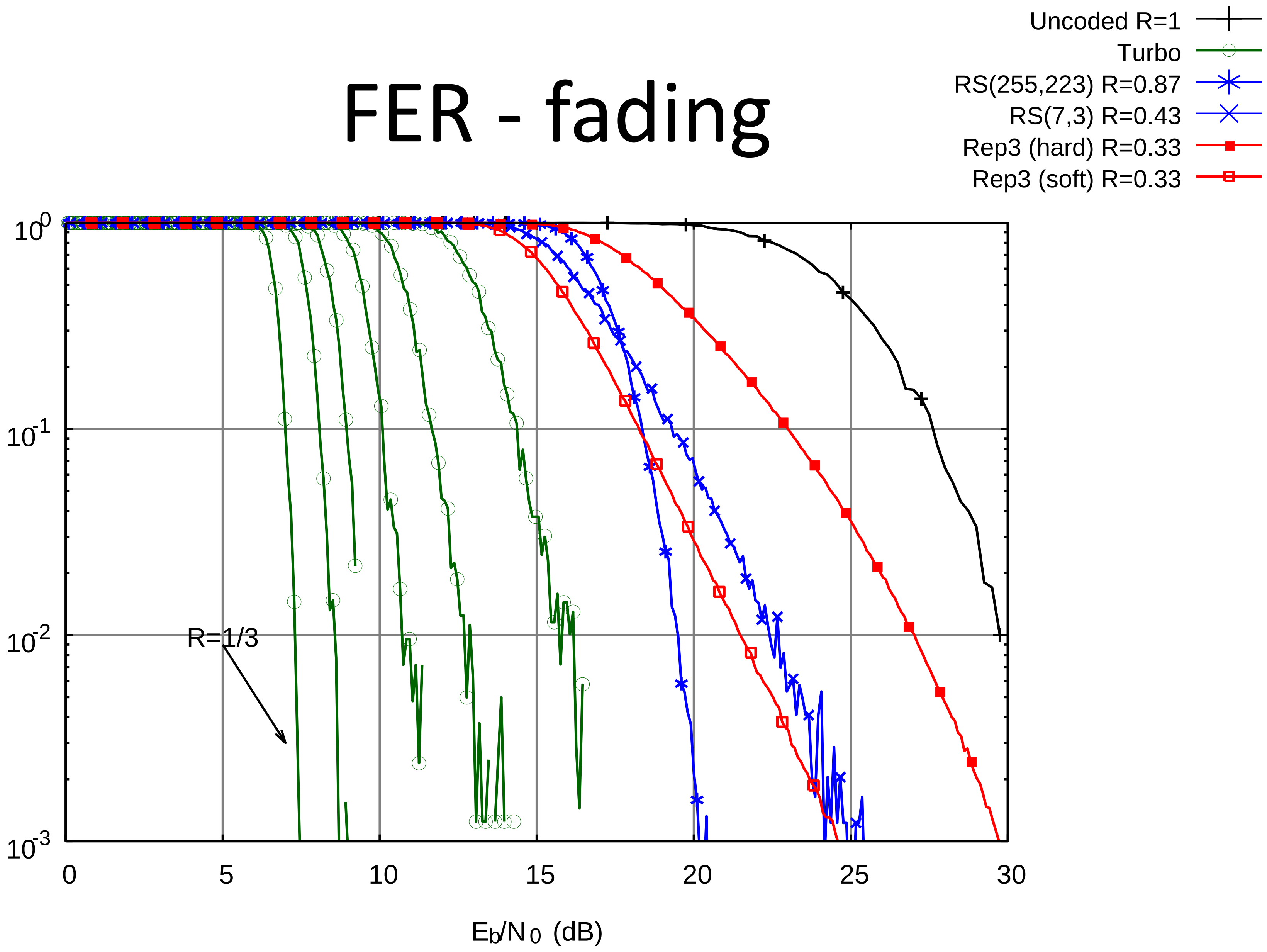
A Fading Channel

- Often swinging or falling payloads produce time fading signals
- Simple model produced to test performance in a fading channel



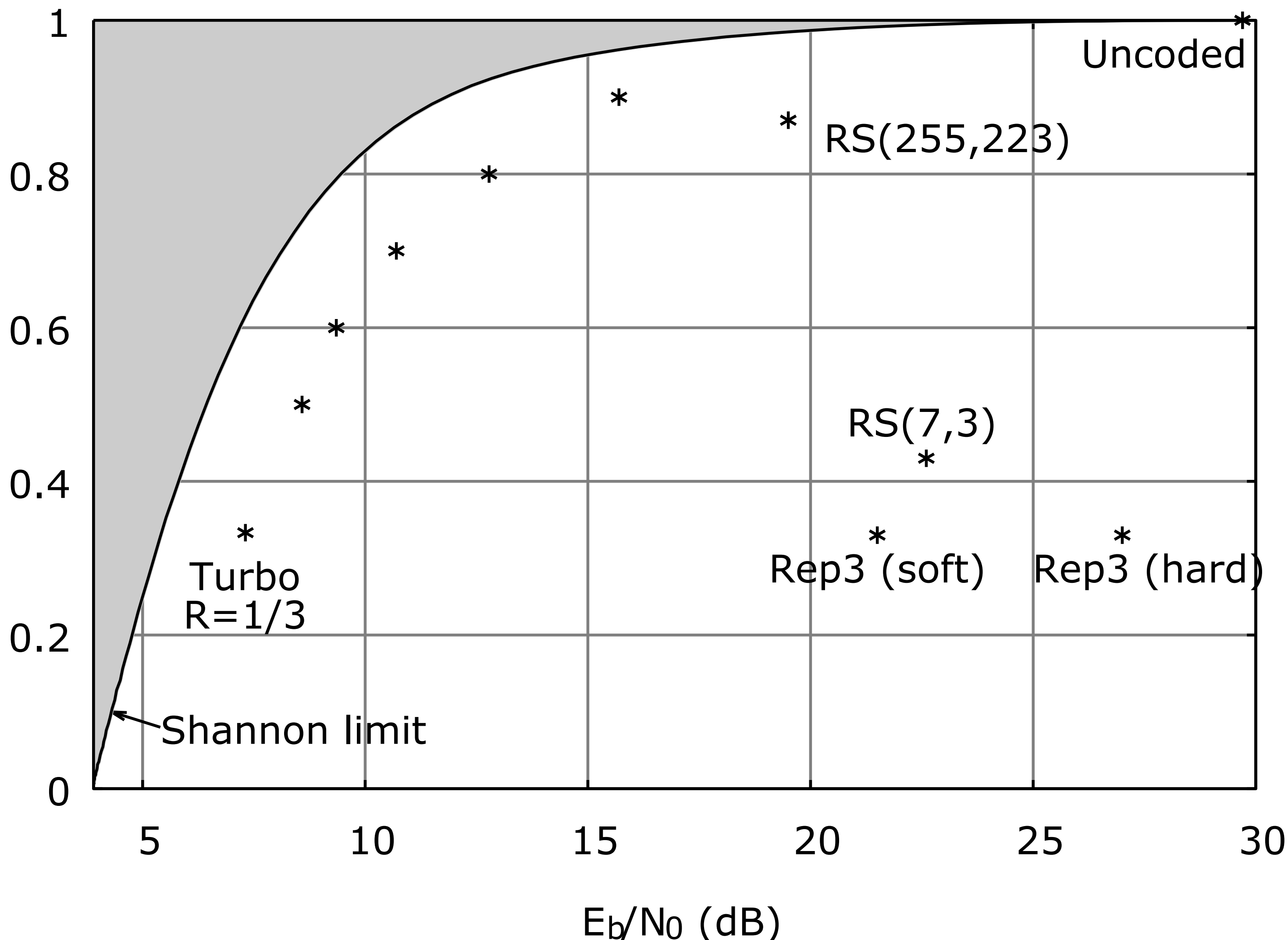


FER - fading



- Fading channel, BPSK, message length = 992 (turbo & RS(7,3)); 1784 (RS(255,223))

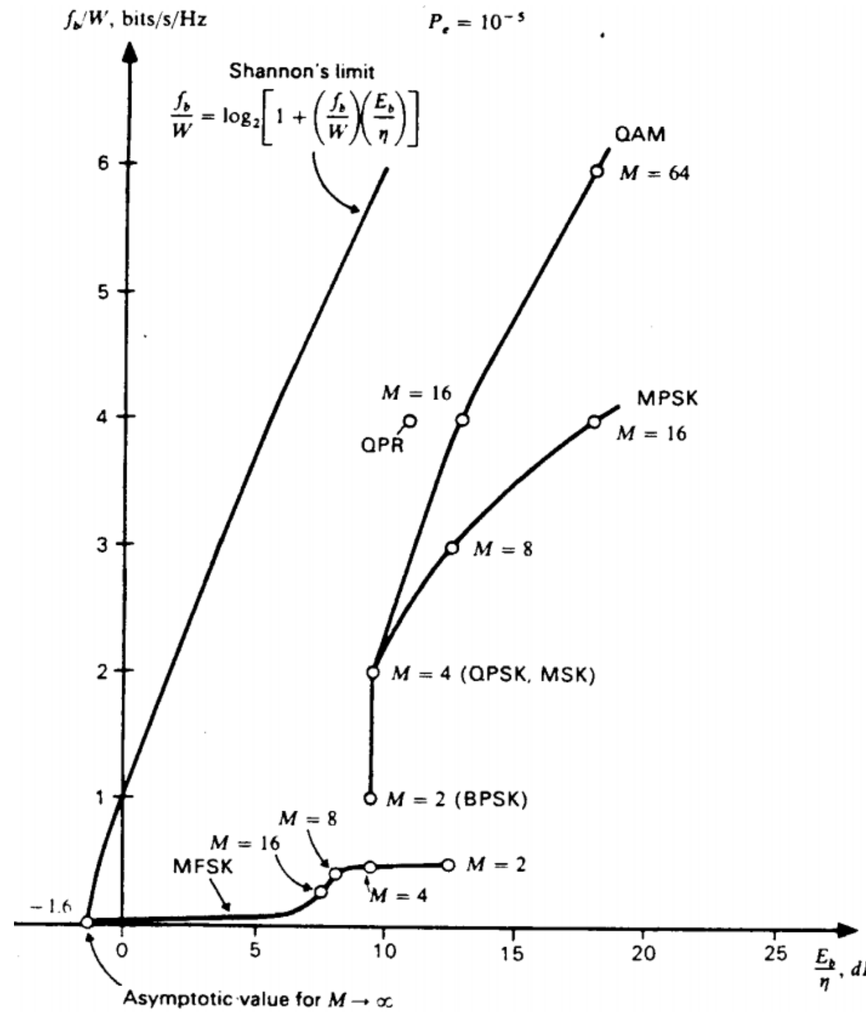
Capacity (Fading)



- fading, BPSK

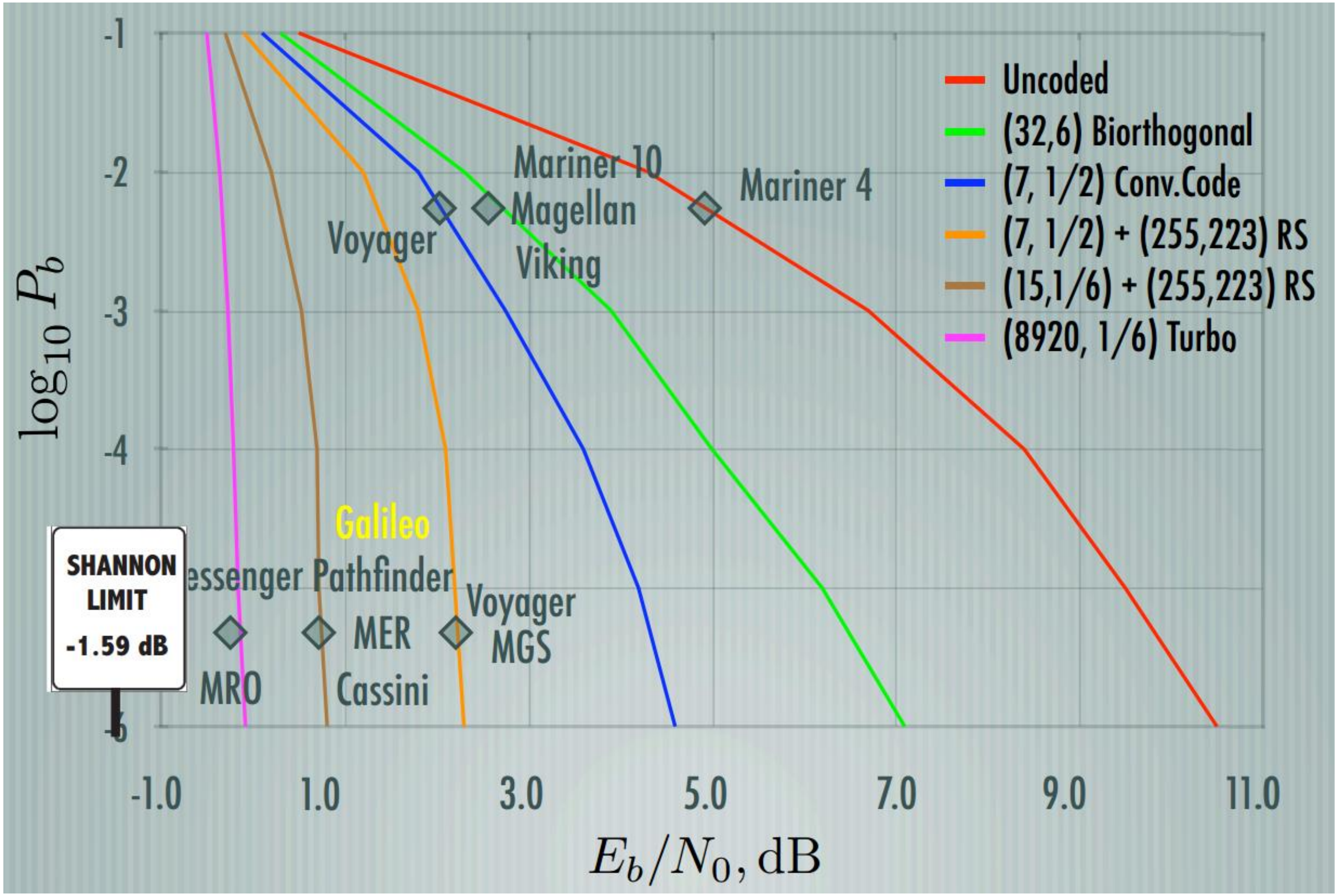
BPSK, FSK and MFSK

- Frequency shift schemes (FSK/MFSK)
  - Power efficient
  - bandwidth inefficient
- Phase/Amplitude shift schemes (BPSK,QAM)
  - Power inefficient
  - Bandwidth efficient



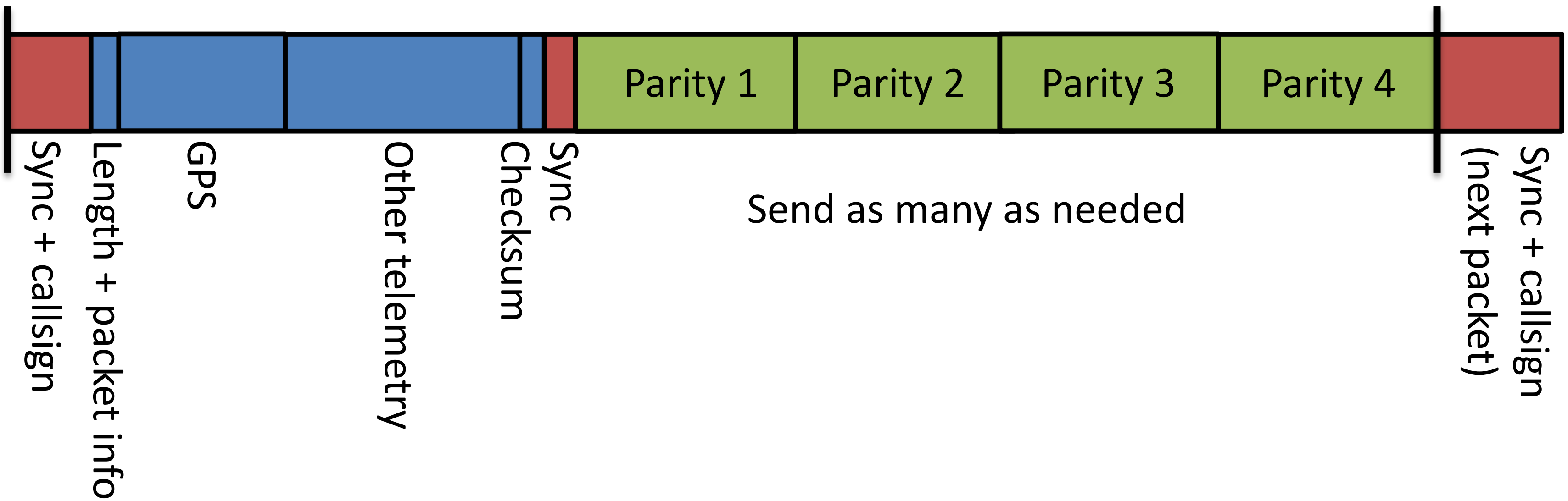
bits/s/Hz vs. E_b/η for Probability of Error = 10^{-5}
taken from "Principle of Communication Systems"
Taub & Schilling, page 482

Deep Space Code Usage



http://www.ee.caltech.edu/EE/Faculty/rjm/papers/Viterbi70.pdf

Potential New Telemetry String



- Turbo code – R ∈ {⅓, ⅖, ½, ⅔, 1}
- Parity bits interleaved and split into four groups
  - Send as many as needed depending on stage of flight
- Ideally keep the same length (of the data part) throughout flight

Concluding Remarks

Questions?

- What goes ‘pieces of 7, pieces of 7’?
  - *A parity error*

Examples of Code Applications

Application	Code	Rate
DVB-T (digital TV)	Reed Solomon & convolutional	1/2 -> 7/8
DVB-T2 / DVB-S2 (digital TV)	LDPC & BCH	1/2 -> 5/6
LTE	Turbo	
WiMAX	Turbo or LDPC	
Voyager	Convolutional (k=5)	1/2
Mars Pathfinder/Cassini probe	Convolutional (k=7)	1/6