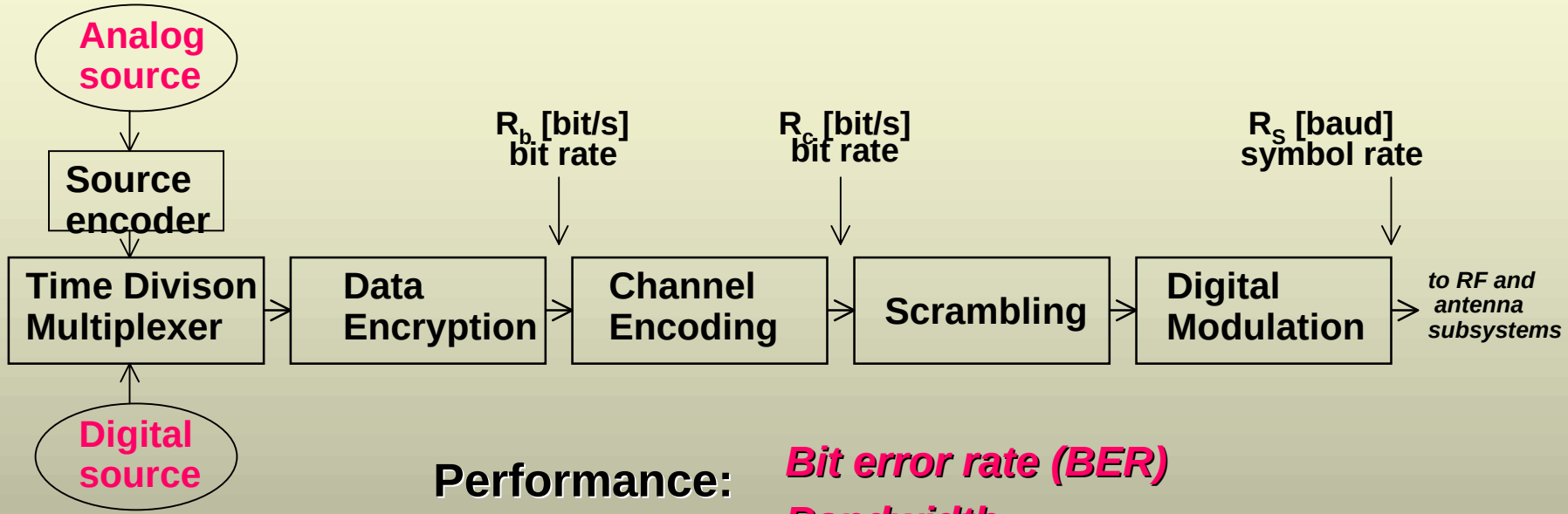
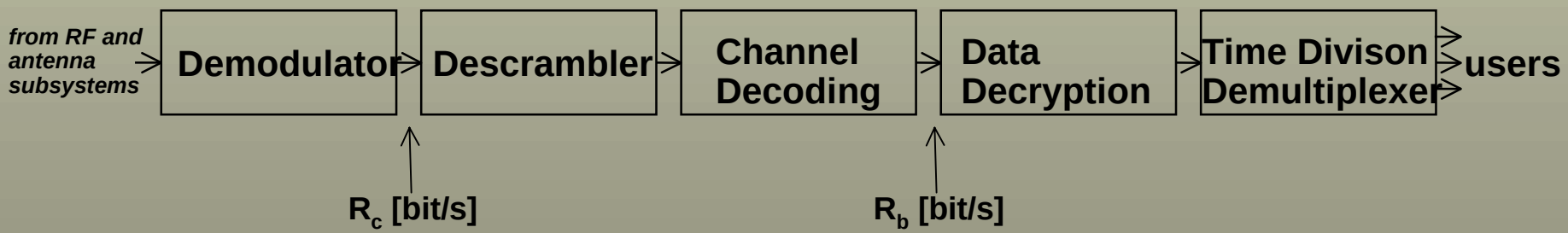
DIGITAL SYSTEM MODEL



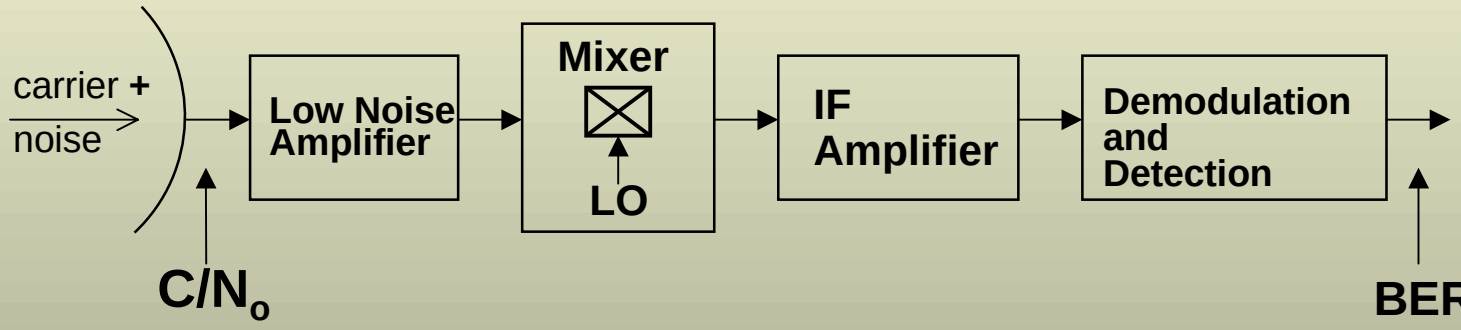
Performance: *Bit error rate (BER)*

Bandwidth



DIGITAL SYSTEM MODEL

Receiver



Energy per bit

Noise power spectral density

$$\frac{E_b}{N_0} = \frac{C/N_o}{R_b}$$

$$BER = f(E_b / N_o)$$

Scrambling

At receiver side clock timing for bit detection is extracted from data symbol transitions. Long data streams of 0`s and 1`s can result in the loss of data synchronization.

Digital data scrambling at transmitter side provides a data symbol transition probability close to 0.5. At receiver side descrambling is performed to restore original data.

Scrambler also removes any periodic pattern in the baseband pulses. Hence it cancels any discrete line component in the modulated RF spectrum. Scrambling is an energy dispersal technique.

Modulation and coding

Types of digital modulation

- ASK - Amplitude Shift Keying
- FSK - Frequency Shift Keying
- PSK - Phase Shift Keying
- QAM - Quadrature Amplitude Modulation

Modulation and coding

AMPLITUDE MODULATION

- Envelope amplitude not used to carry information becouse of non-linear effects

PHASE MODULATION

- good performance
- approx. constant envelope
- phase noise is a problem
- carrier tracking is required (coherent case)
- non-coherent demod. has implementation penalty

FREQUENCY MODULATION

- constant envelope
- carrier tracking not necessery
- insensitive to phase noise

Modulation and coding

Spectral Efficiency

$$\Gamma = R/B \quad [bit/sHz]$$

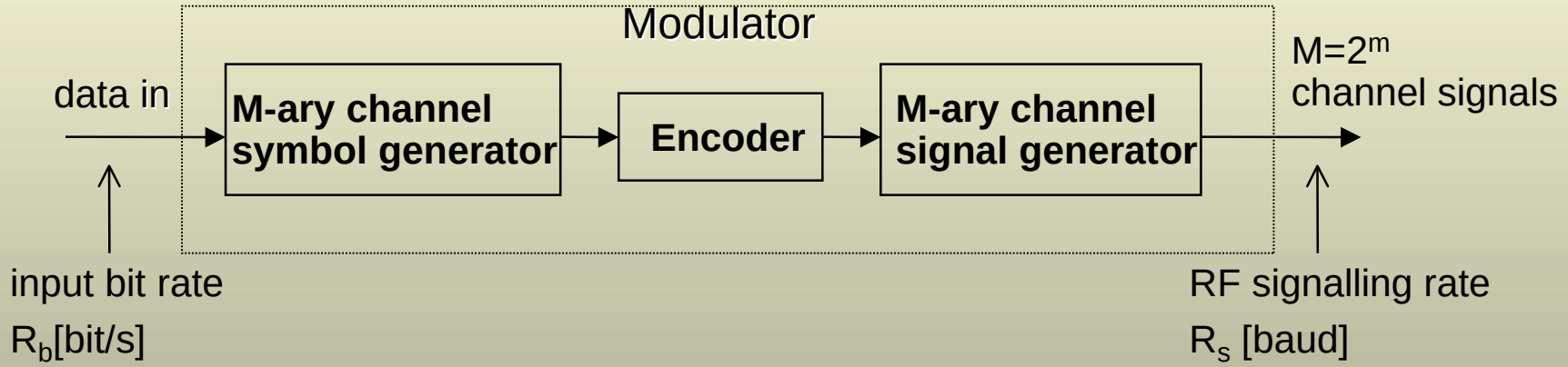
R - transmitted bit rate

B - the bandwidth occupied by the carrier

The *spectral efficiency* expresses the ability of the modulated carrier to convey a given bit rate within a given bandwidth.

Modulation and coding

M-ary Modulation



The Encoder provides a one-to-one mapping of the channel symbols.

Each channel signal conveys m bits:

$T_S = mT_b$ where T_S and T_b are bit and symbol durations

$R_S = R_b/m$

Modulation and coding

Digital Phase Modulation is well suited to the satellite link as it offers:

- **constant envelope**
- **high bandwidth efficiency**

Main PSK types used:

- BPSK biphase phase shift keying (M=2)

- QPSK quadriphase phase shift keying (M=4)

OQPSK offset QPSK

π/4QPSK

For BPSK and QPSK: $BER = 1/2\,\mathrm{erfc}\sqrt{E_b/N_0}$

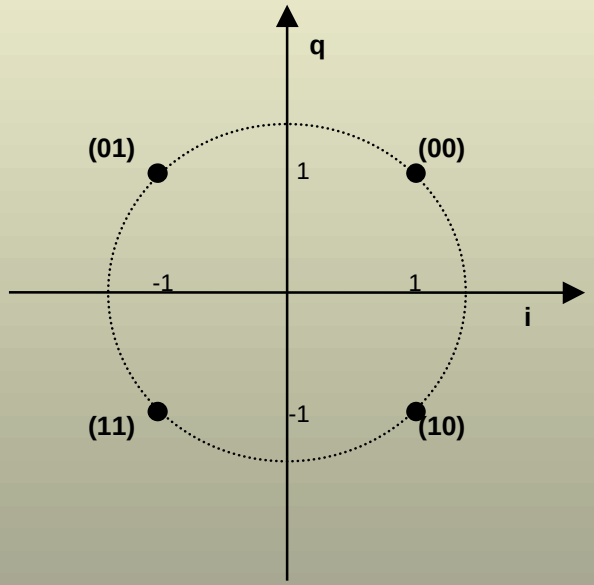
When considering M-ary PSK (M>2) the error rate performance can be specified in terms of the symbol error rate (SER), and approximate relationship is: $BER = SER/\log_2(M)$

Modulation and coding

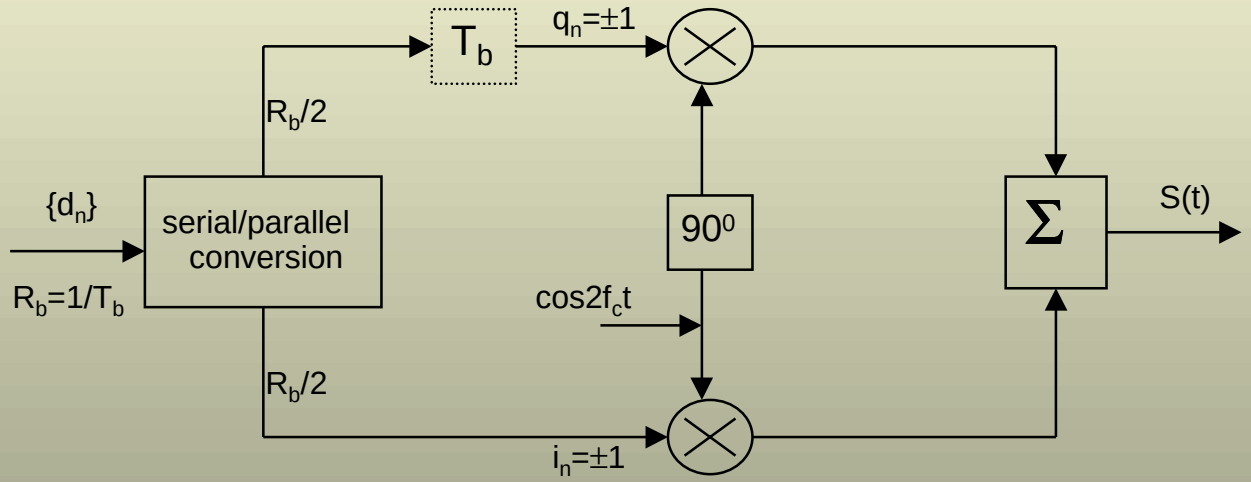
Coherent demodulation

Differential demodulation

Modulation and coding

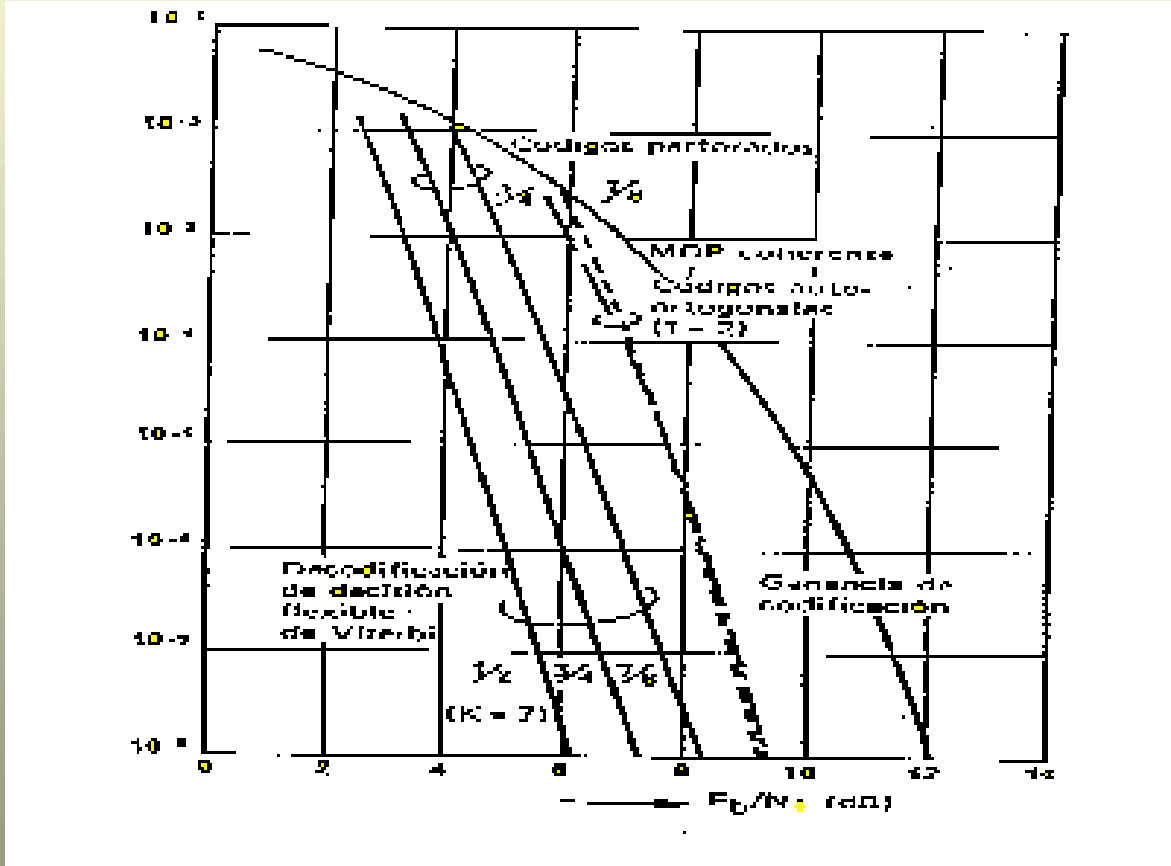


QPSK constellation



QPSK/OQPSK modulator

Modulation and coding



Modulation and coding

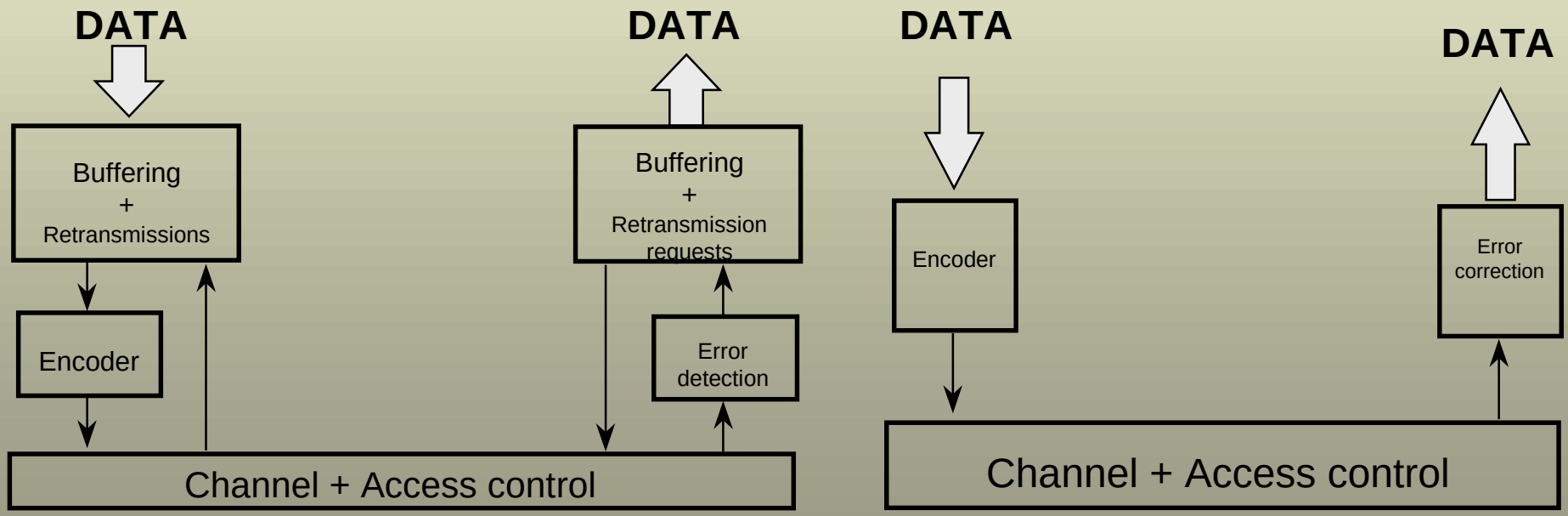
Error Detection/Correction Techniques

- **ARQ** - **Automatic Repeat on Request**

- **FEC** - **Forward Error Correction**
  - **block codes**
  - **convolutional codes**
  - **turbo codes**

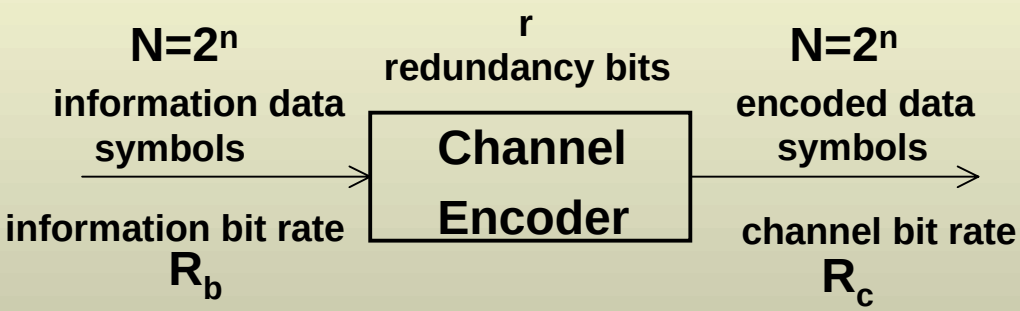
Modulation and coding

ARQ and FEC Techniques



Modulation and coding

Channel Encoding



N - numer of information bits r - number of redundancy bits

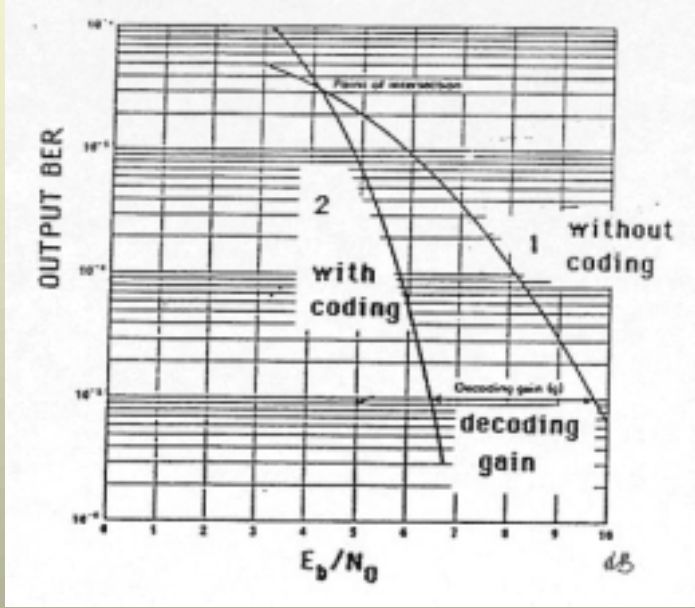
Channel encoder inserts redundancy bits for purposes of *error control* and *error correction*.

Code rate $k = n/(n+r)$

$$R_c = R_b/k$$

Modulation and coding

Coding Gain

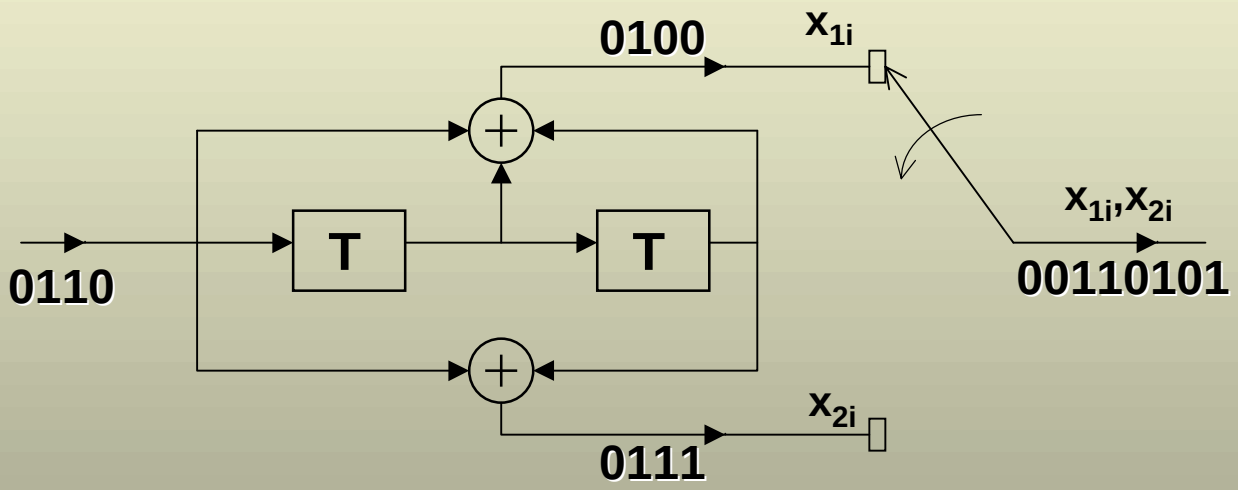


Typical values:

Code rate k	Required E_b/N_0 for BER=10^{-5}	Decoding gain
1	9.6dB	0dB
7/8	7.6dB	2dB
3/4	5.8dB	3.8dB
2/3	5.3dB	4.3dB
1/2	4.9dB	4.7dB

Modulation and coding

Convolutional Encoder



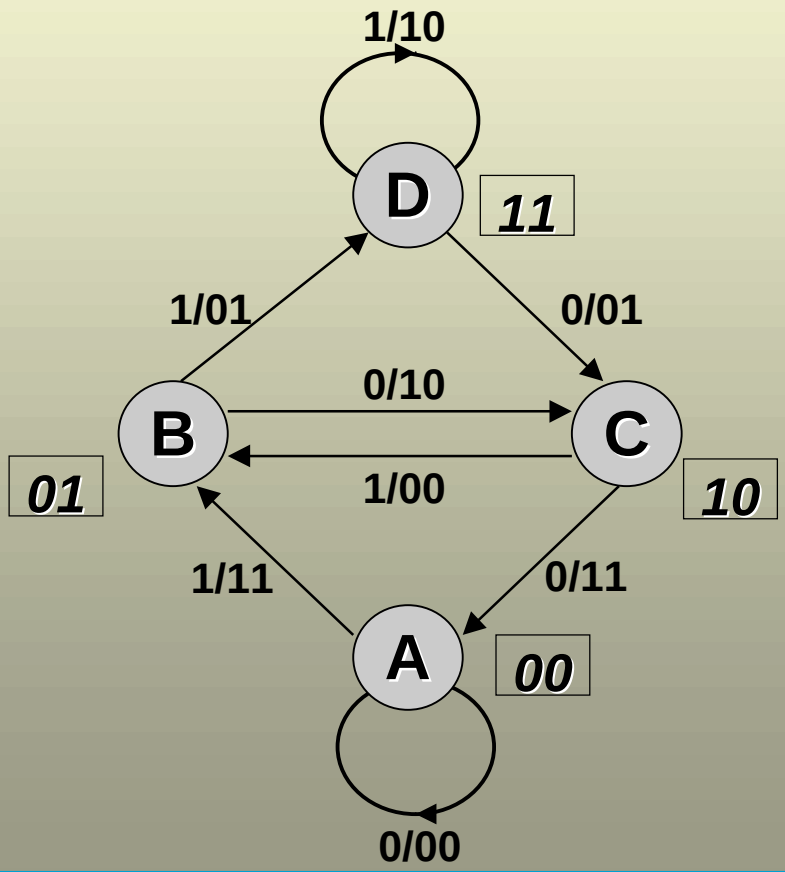
K=1 N=2 M=3
k=K/N

$G_1(X) = 1 + X + X^2$ $(G_1 = 1\ 1\ 1)$

$G_2(X) = 1 + X^2$ $(G_2 = 1\ 0\ 1)$

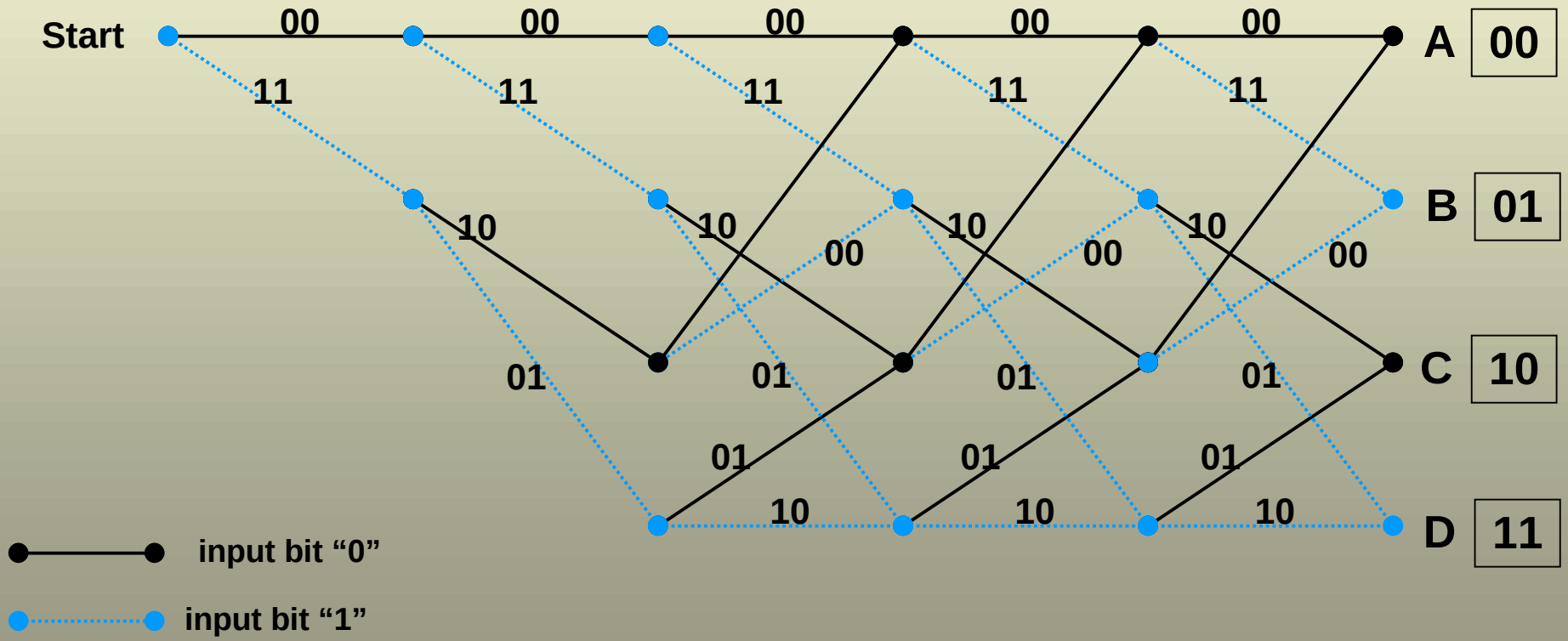
Modulation and coding

Convolutional Code



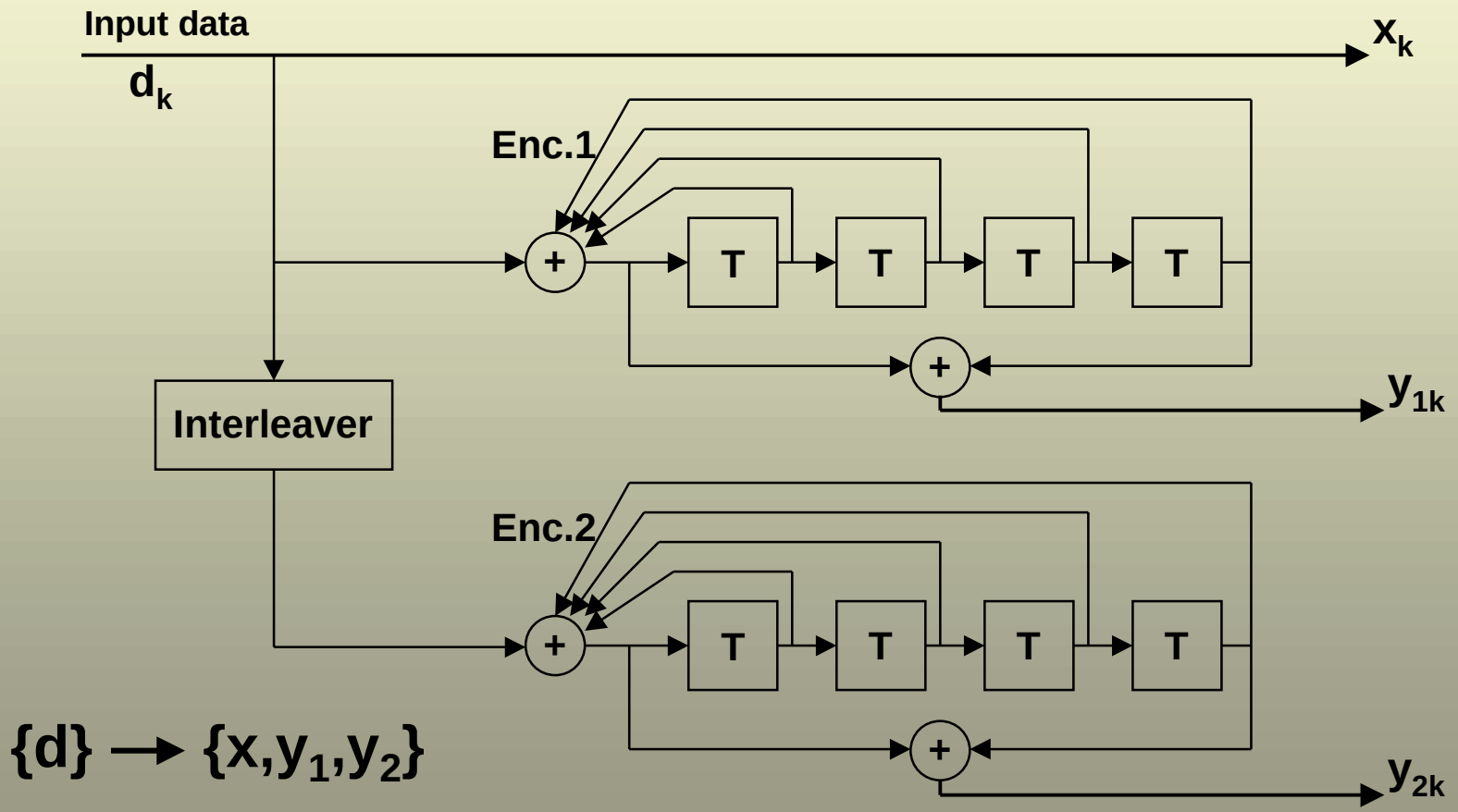
Modulation and coding

Convolutional Code



Modulation and coding

Turbo Encoder



Modulation and coding

Turbo Decoder