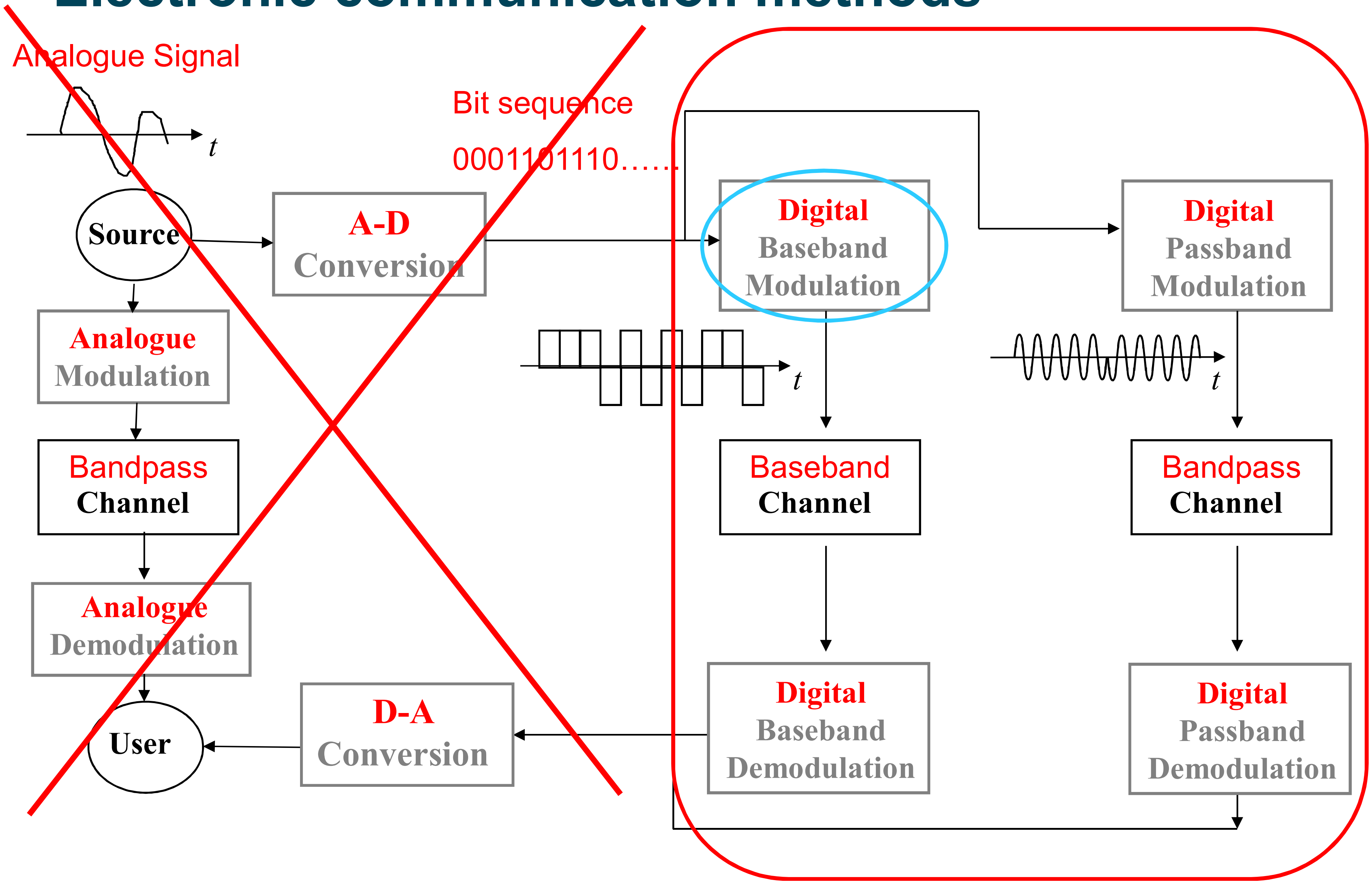
Wireless Communications Principles

Digital Baseband Transmission

Electronic communication methods

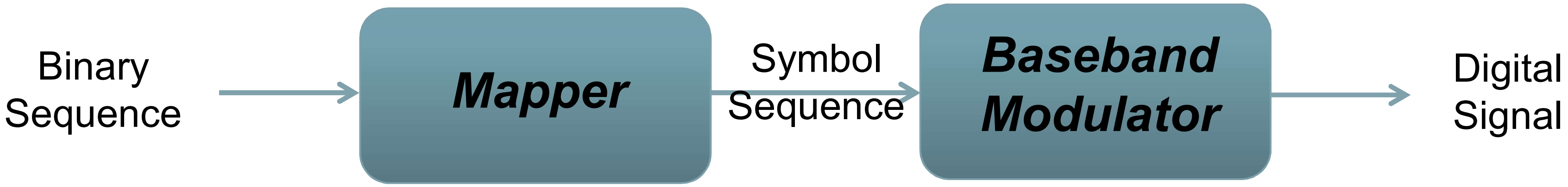


How to Choose a Baseband Digital Transmission Scheme?

- Criteria to take into account when choosing the digital modulation method:
  - Energy efficiency, i.e., the E_b/N_0 ratio required to achieve a specific error probability
  - Bandwidth efficiency, i.e., the data rate per unit bandwidth
  - Implementation cost and complexity
- Conflicting requirements that cannot be satisfied simultaneously

Baseband Digital Transmission

Generic Representation of a Baseband Modulator



- The baseband digital signal is given by:

$$x(t) = \sum_{k=-\infty}^{\infty} X_k \cdot p(t - kT_s)$$

- where $p(t)$ is a (unit-energy) baseband pulse with duration T_s.

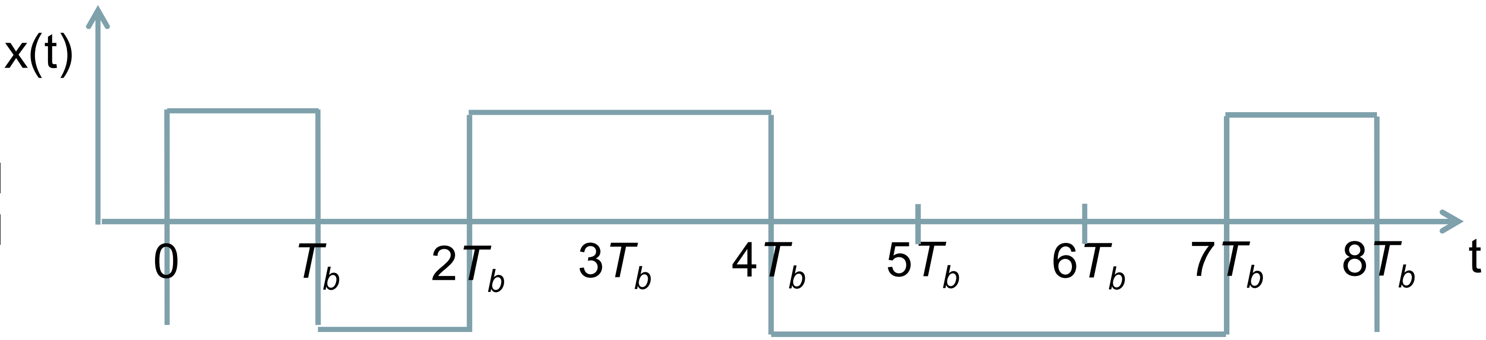
- The symbols X_k are drawn from an alphabet $\mathcal{A}=\{A_1,A_2,\ldots,A_M\}$ with cardinality M, where each symbol encodes a group of $\log_2 M$ bits.

NB: The sequence of symbols X_k is assumed to be stationary.

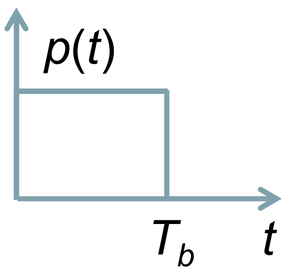
Baseband Digital Transmission: Example 1

Binary Sequence	1	0	1	1	0	0	0	1
Symbol Sequence	1	−1	1	1	−1	−1	−1	1

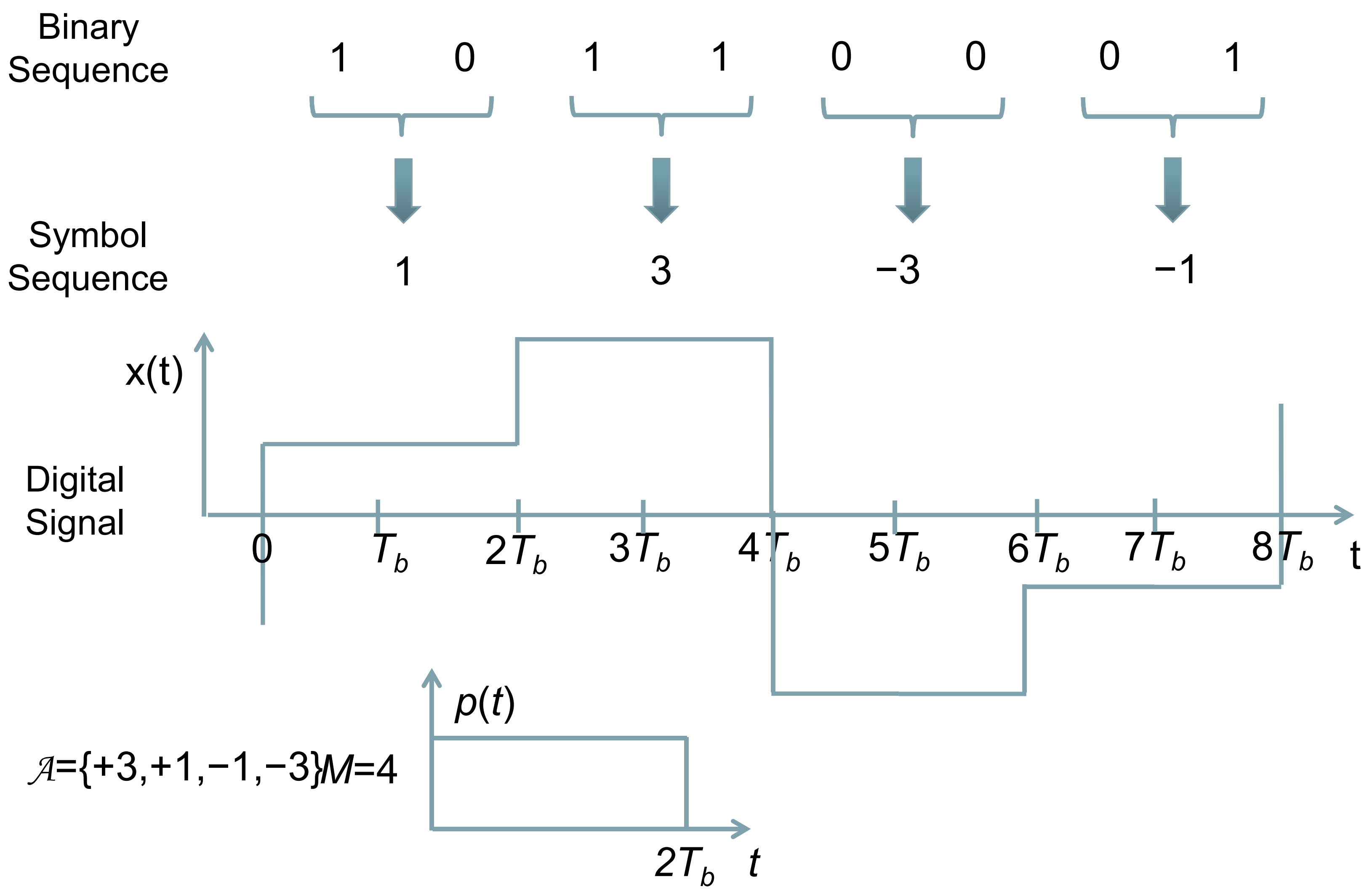
Digital Signal



$\mathcal{A}=\{+1,-1\}$ $M=2$



Baseband Digital Transmission: Example 2



Baseband Digital Transmission

- The digital transmission schemes can be classified as follows:
  - *Binary schemes*: a single bit is transmitted in a signaling interval (M=2)
  - M-*ary schemes*: multiple bits are transmitted in a signaling interval (M>2)
  - *Schemes without memory*: The mapping from a sequence of $\log_2 M$ bits to a symbol depends exclusively on the current sequence of $\log_2 M$ bits;
  - *Schemes with memory*: The mapping from a sequence of $\log_2 M$ bits to a symbol depends both on the current sequence of $\log_2 M$ bits as well as on past bits;
  - *Linear schemes* require that the principle of superposition apply in the mapping of the digital sequence into successive waveforms;
  - *Nonlinear schemes* do not require that such superposition applies.
- The focus is predominantly on ***binary and M-ary linear memoryless*** schemes.

Relevant Properties

- Symbol/Bit Rate
- Symbol/Bit Duration
- Energy Conveyed per Symbol
- Energy Conveyed per Bit
- Spectral Characteristics
- Bandwidth Usage

Symbol & Bit Rate / Duration

- The symbol rate R_s corresponds to the number of symbols transmitted per unit of time:

$$R_s = 1/T_s$$

- where T_s is the symbol interval, i.e. the duration of a symbol.

- The bit rate R_b corresponds to the number of bits transmitted per unit of time:

$$T_b = 1/R_b$$

- where T_b is the bit interval, i.e. the duration of a bit.

- These quantities are related as follows:

$$R_b = \log_2 M \cdot R_s \qquad\qquad T_b = T_s/\log_2 M$$

Average Power, Energy per Bit and Energy per Symbol

- The average power associated with the digital signal is given by:

$$P = \frac{1}{T_s} \int_{T_s} E\left\{x^2(t)\right\} dt = \frac{1}{T_s} E\left\{X_k^2\right\} = \frac{1}{T_s} \sum_{a \in A} a^2 \Pr\left(X_k = a\right)$$

- The average energy per symbol is:

$$\xi_s = T_s P = P / R_s = E\left\{X_k^2\right\}$$

- The average energy per bit is:

$$\xi_b = T_b P = P / R_b = \frac{1}{\log_2 M} E\left\{X_k^2\right\}$$

NB: It is assumed that p(t) is a (unit-energy) baseband pulse with duration T_s.

Binary Transmission Schemes

- The alphabet is $\mathcal{A}=\{A_1,A_2\}$ ($M=2$), where A_1 and A_2 are specific amplitude levels.

- One of the amplitudes encodes the *bit 1* and the other amplitude encodes the *bit 0*.

- Two popular baseband binary transmission schemes, namely unipolar and polar baseband signaling schemes, are associated with different *alphabets*.

Unipolar Binary Transmission

- In unipolar baseband signaling schemes A_1=A and A_2=0, where A is a specific amplitude level.

- The average energy associated with a unipolar signaling scheme (assuming that the symbols A_1=A and A_2=0 are equally likely) is
$$\xi_s = \xi_b = A^2/2$$

NB: It is assumed that p(t) is a (unit-energy) baseband pulse with duration T_s.

Polar Binary Transmission

- In polar baseband signaling schemes A_1=A and A_2=−A, where A is a specific amplitude level.

- The average energy associated with a unipolar signaling scheme (assuming that the symbols A_1=A and A_2=−A are equally likely) is $\xi_s = \xi_b = A^2$

NB: It is assumed that p(t) is a (unit-energy) baseband pulse with duration T_s.

M-*ary* Transmission Schemes

- The alphabet is $\mathcal{A}=\{A_1,A_2,\ldots,A_M\}$ ($M>2$), where A_1, A_2 ,…,A_M are specific amplitude levels.

- A common choice for the amplitudes is

$$A_m = (2m-1-M)A, \qquad m = 1, 2, \ldots, M$$

- Then, the average energy per symbol is given by

$$\xi_s = \frac{M^2-1}{3}A^2$$

- and the average energy per bit is given by

$$\xi_b = \frac{M^2-1}{3\log_2 M}A^2$$

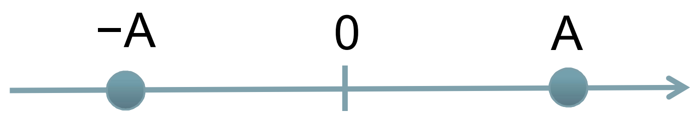
NB: It is assumed that p(t) is a (unit-energy) baseband pulse with duration T_s. It is also assumed that the symbols A_1, A_2 ,…,A_M are equally likely.

Constellations

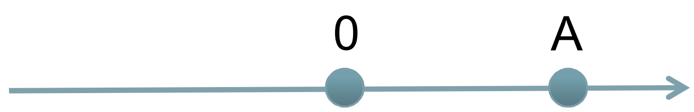
- A constellation diagram depicts the various symbols associated with a signaling scheme.

- It is useful to visualize baseband digital transmission schemes
  - but more important for bandpass digital schemes (later in the course).

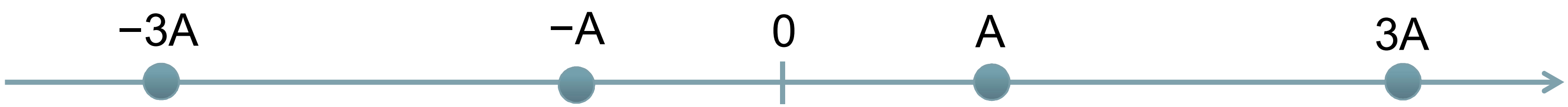
Constellation: Polar Signaling



Constellation: Unipolar Signaling



Constellation: M-*ary* Signaling (M=4)



Self-Assessment Example

Information is in an analogue waveform, whose maximum frequency is f_m = 4 kHz. It is to be transmitted using a 4-ary PAM system. 4 bits are used to represent each sample of the signal.

(1) What is the minimum required sampling rate and what is the resulting bit rate?

(2) What is the 4-ary PAM symbol transmission rate?

(3) What is the minimum channel bandwidth required for binary and 4-ary PAM systems?

(4) Determine the amplitude of the pulses required for polar binary PAM and 4-ary PAM if the transmission power is fixed at 16W.

(5) Calculate the energy per symbol and energy per bit for both modulation schemes.