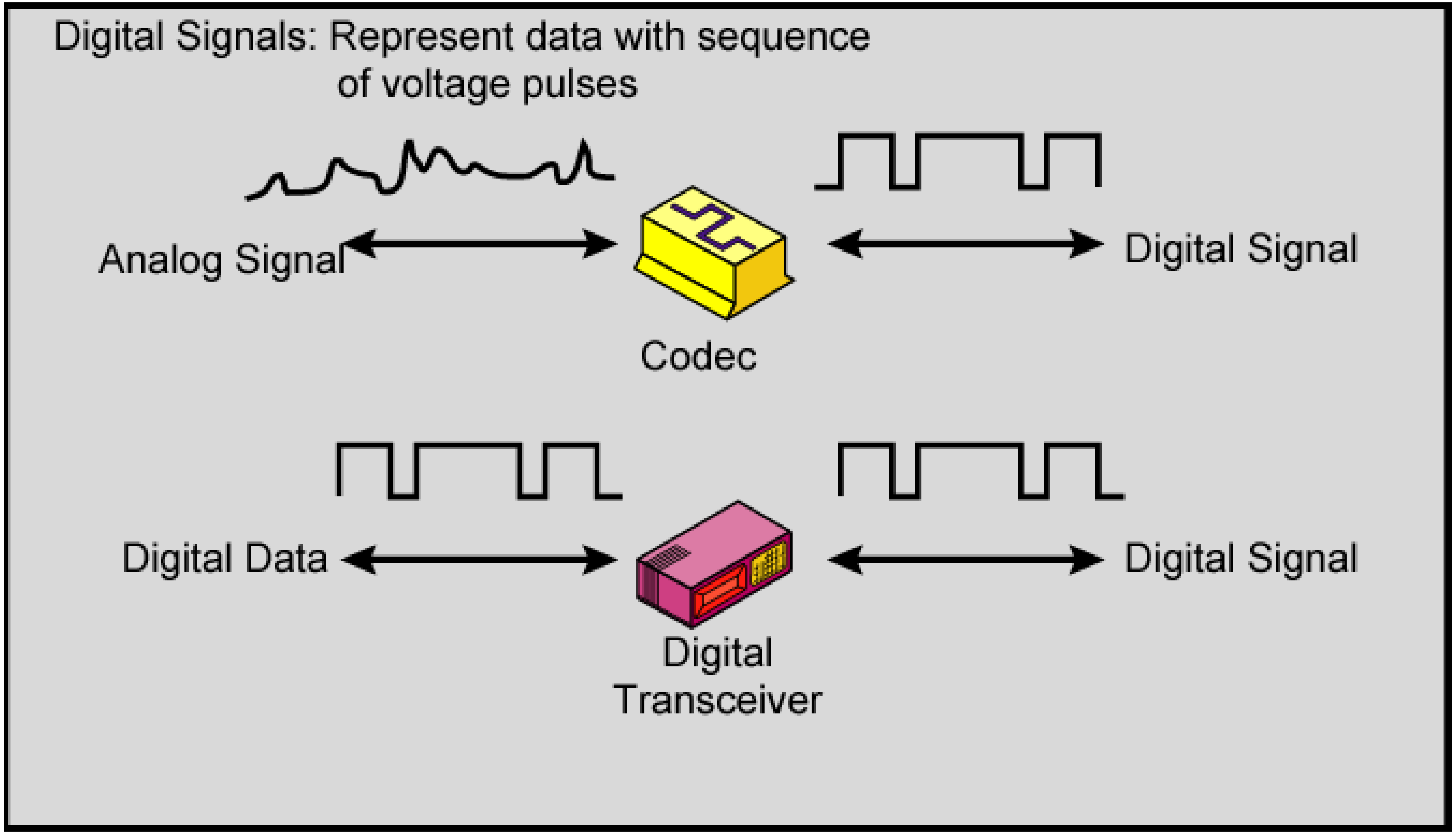
Digital Transmission

Channel Capacity

- How to find coding scheme that achieves Shannon capacity?
- How fast can bits be transmitted reliably over a given transmission system?
  - Amount of energy put in transmitting the system
  - Amount of noise that receiver has to deal with
  - Distance that the signal has to be transmitted over
  - Bandwidth of the transmission channel
- If bandwidth of channel is B, max rate of transmission is 2B pulses/sec
- Infinite data rate by increasing number of bits/pulse
- Practically limited by SNR, non-linear effects, receiver sensitivity, transmitter capability, choice of medium.

Digital Signals



Sampling and Quantization
Line coding

Line coding

Digital Transmission

- Discrete, discontinuous voltage pulses called signal elements
- Data levels: voltage levels that actually represent bits
- Multi-level schemes: many bits per pulse
- Unipolar: All signal elements have same polarity
- Polar: positive and negative voltage levels for different elements
- Modulation rate: signal elements per sec (measured in baud)

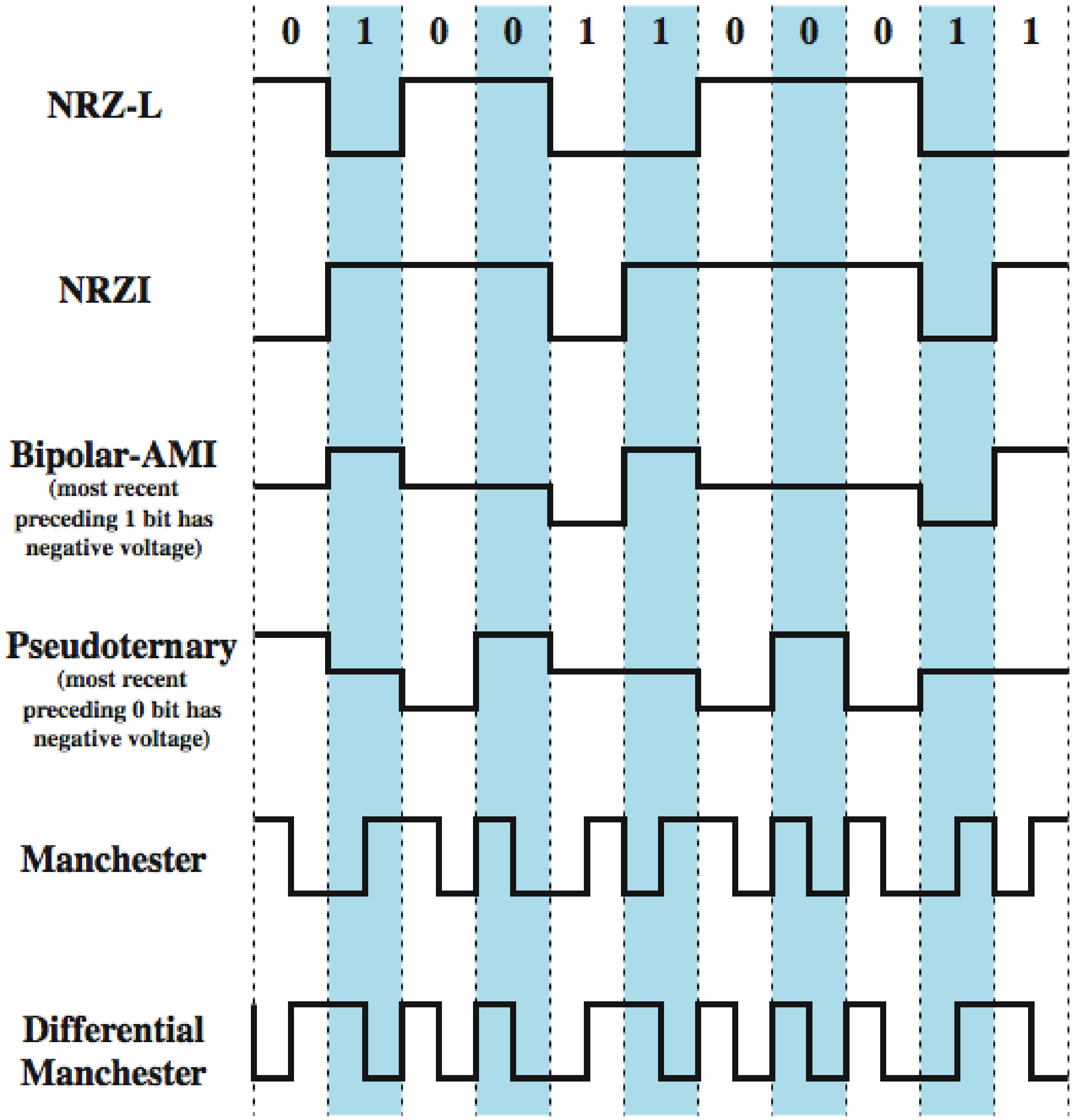
Digital Signal Properties

- Timing of bits : When does a bit start and end?
  - Synchronous and Asynchronous transmission
- Signal levels: Is the level for a bit high or low? (differential)
- Affected by data rate, bandwidth, SNR, synchronization
- Encoding: converting binary data into digital signal
- Objectives of encoding
  - Maximize data rate in a given bandwidth
  - Robustness to noise – minimize bit error rate
  - Lower complexity and cost
  - Other properties like self-synchronization, zero DC, error detection
  - Tune signal spectrum: concentrate power at mid-frequencies

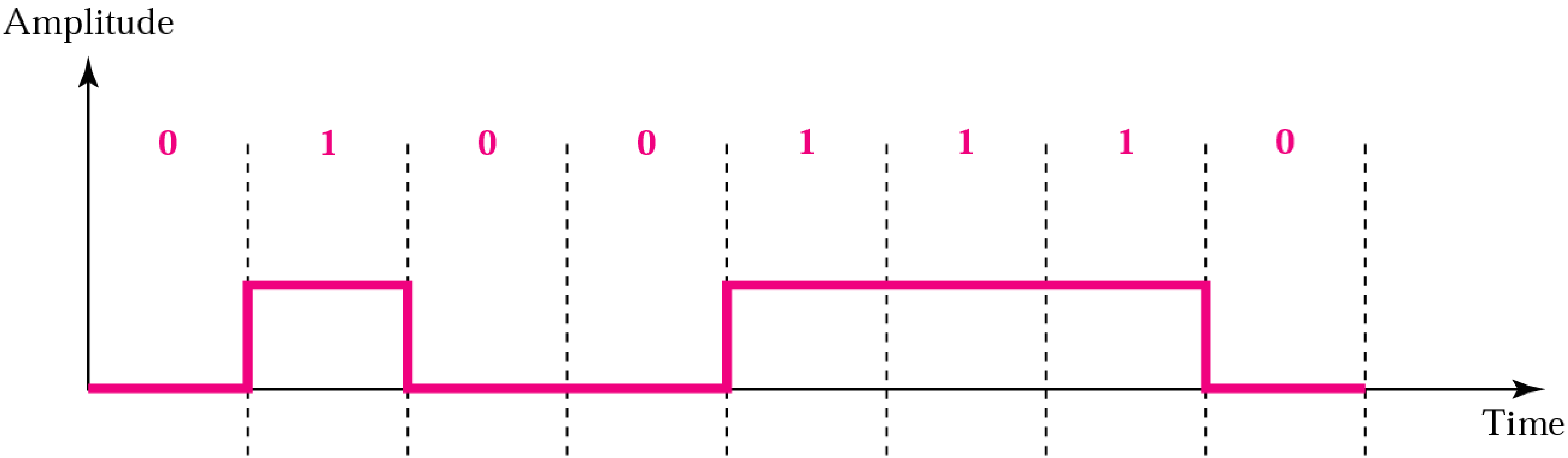
Encoding Considerations

- Data rate – Bandwidth – BER tradeoff
  - Increase in data rate increases bit error rate BER
  - Increase in SNR decreases BER
  - Increase in bandwidth increases data rate but also increases noise
- Signal spectrum
  - Lack of DC components
  - Lack of high frequency components
- Clocking/synchronization
- Error detection
- Noise immunity
- Cost and complexity

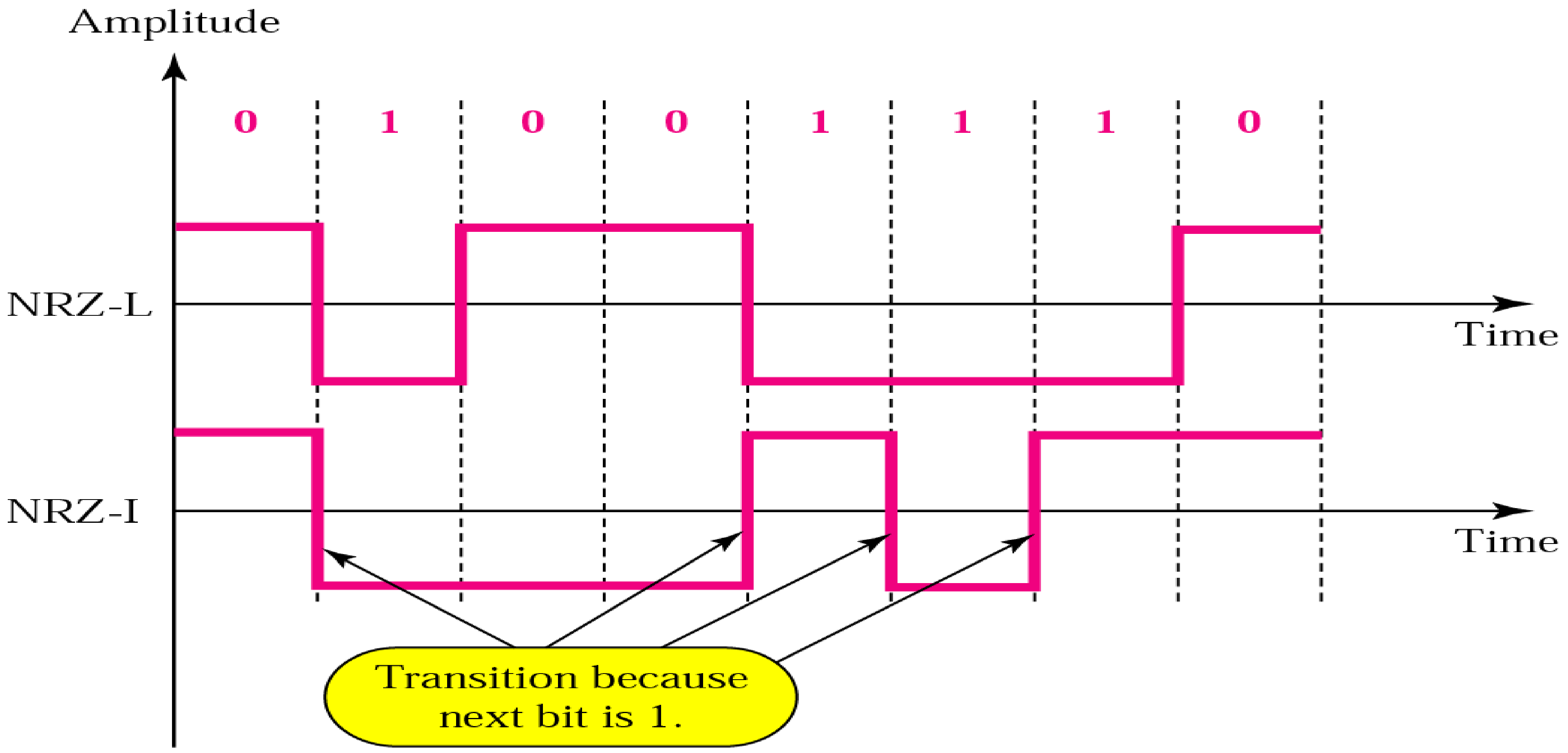
Encoding schemes



Unipolar-NRZ



Polar-NRZ

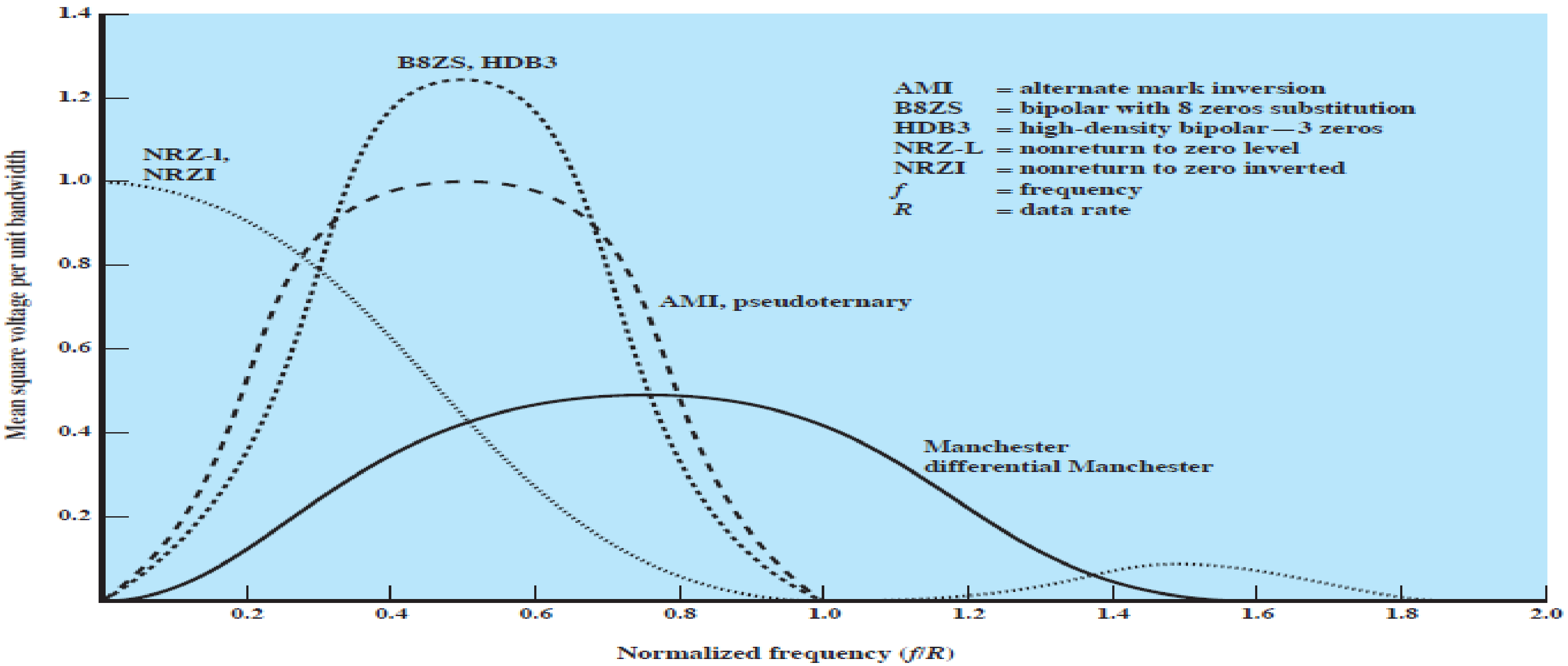


differential encoding: data represented by changes rather than levels

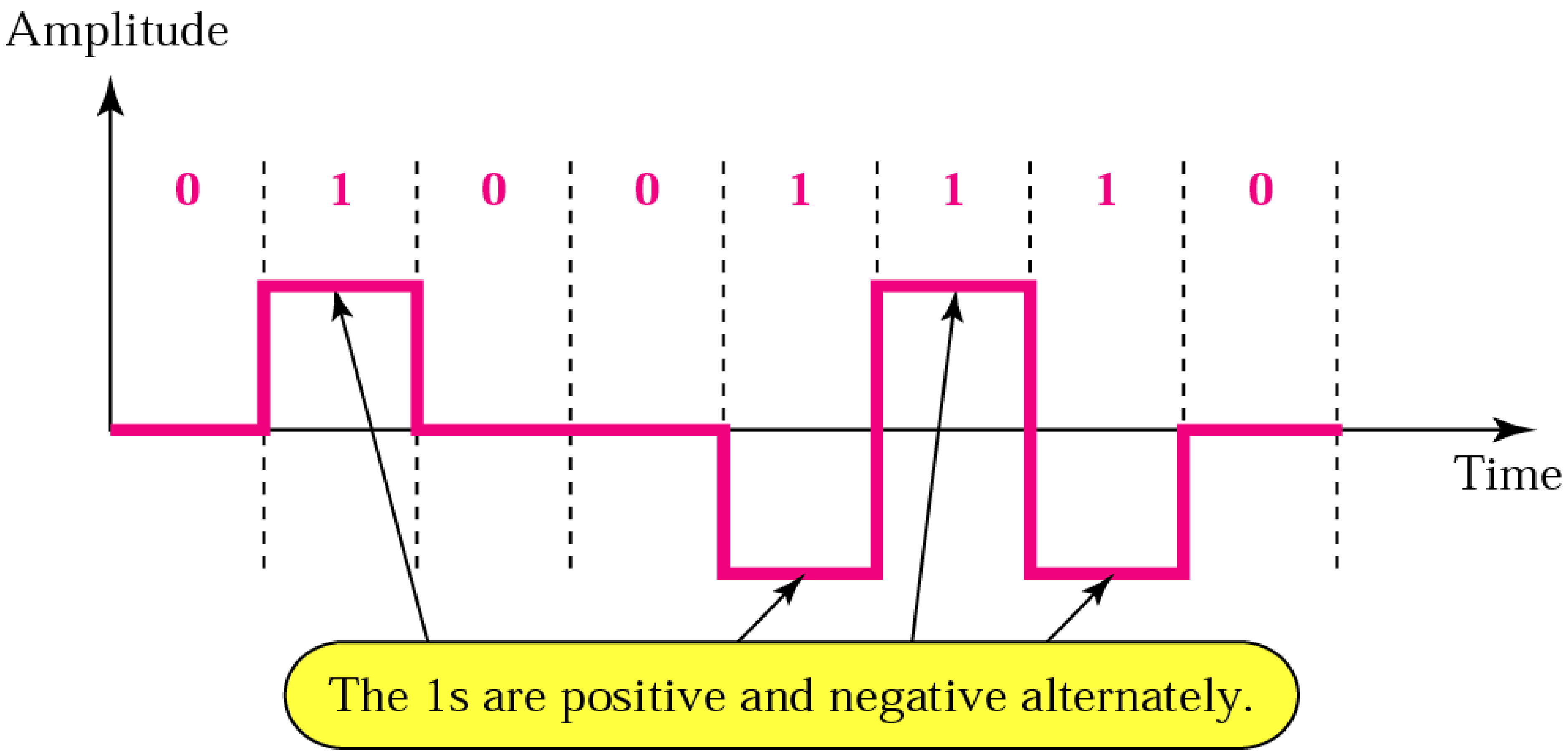
- more reliable detection of transition rather than level
- easy to lose sense of polarity due to wrong wiring

NRZ codes

- Pros: easy to engineer, good use of bandwidth
- Cons
  - dc component
  - lack of synchronization capability
- used for magnetic recording, not often for signal transmission



Bipolar-AMI (and Psuedoternary)

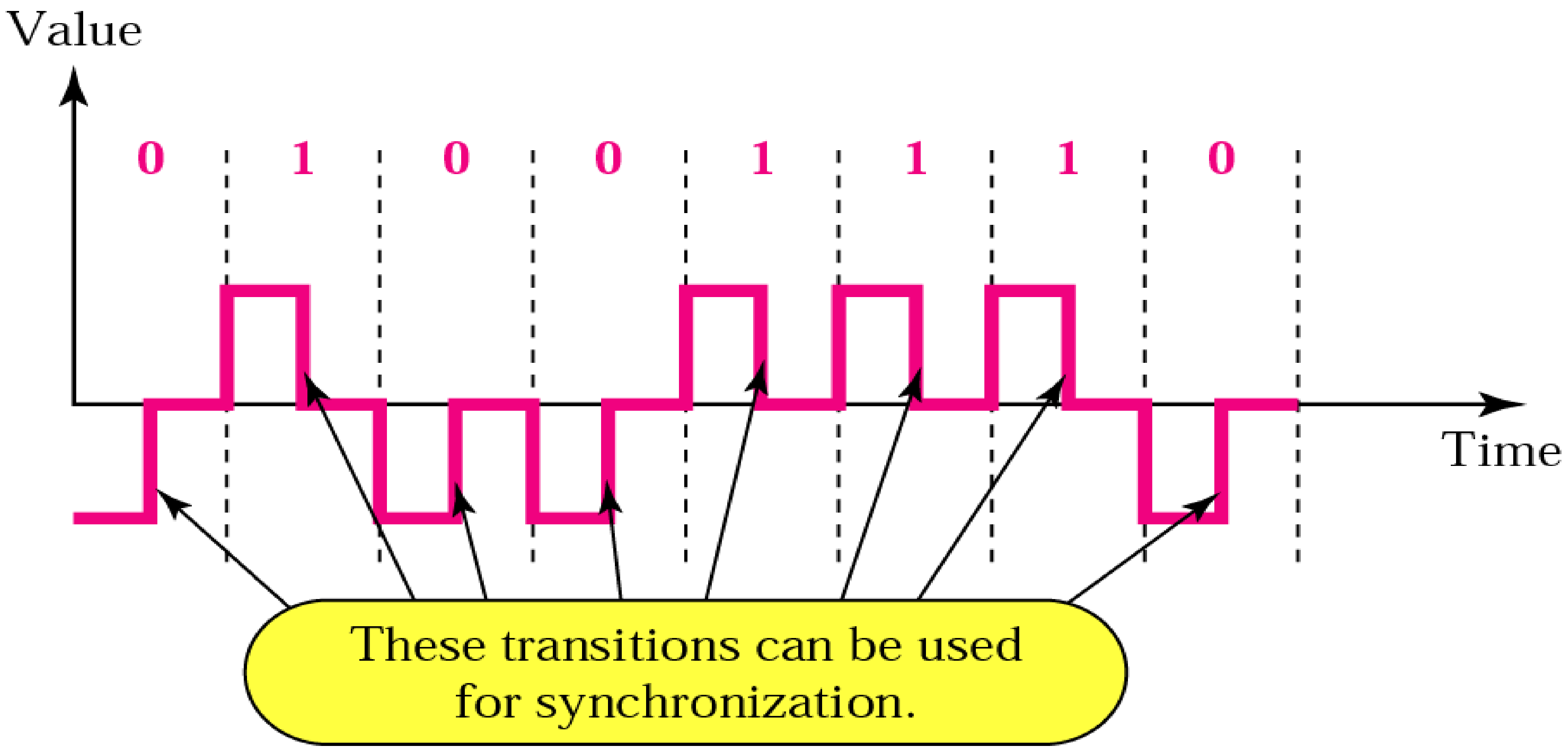


- No DC Component
- Lower bandwidth than NRZ codes
- Easy error detection
- Long runs of 0s still a problem

Biphase coding schemes

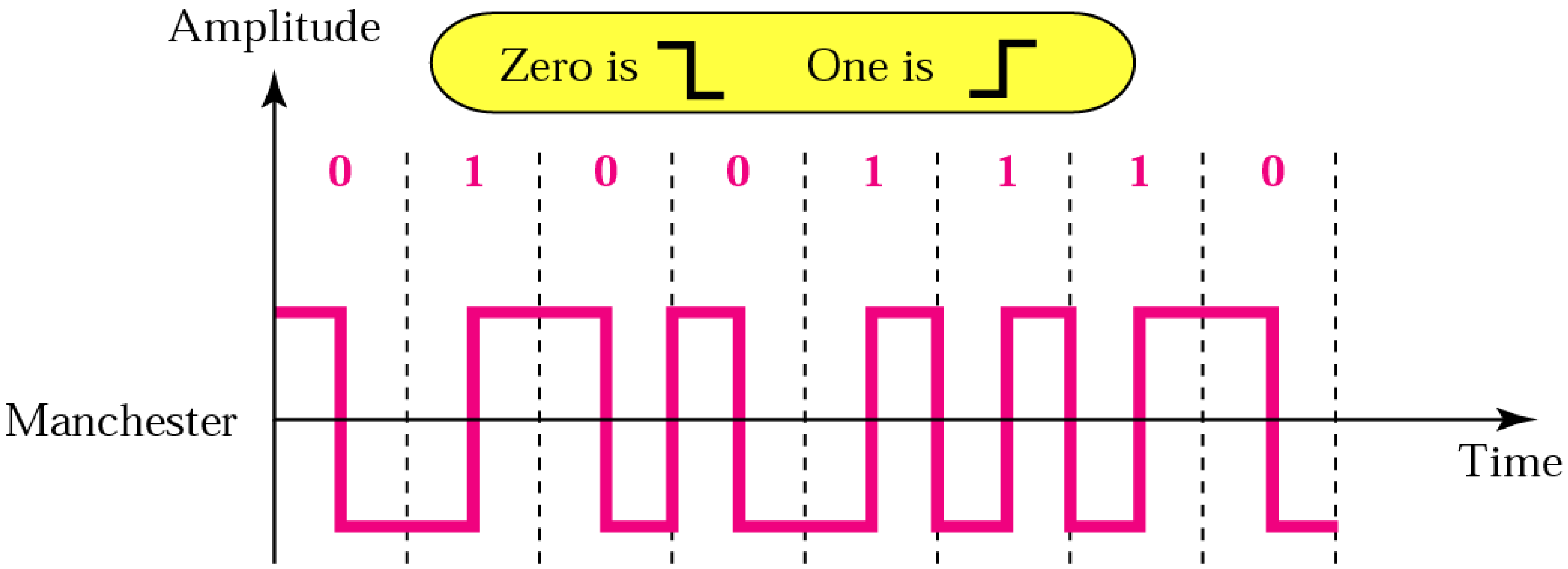
- Transition at the middle of each bit period
- Predictable transition helps receiver synchronization
- No DC component
- Absence of expected transition helps identification of bit flip
- Used popularly in Ethernet

Bipolar-RZ



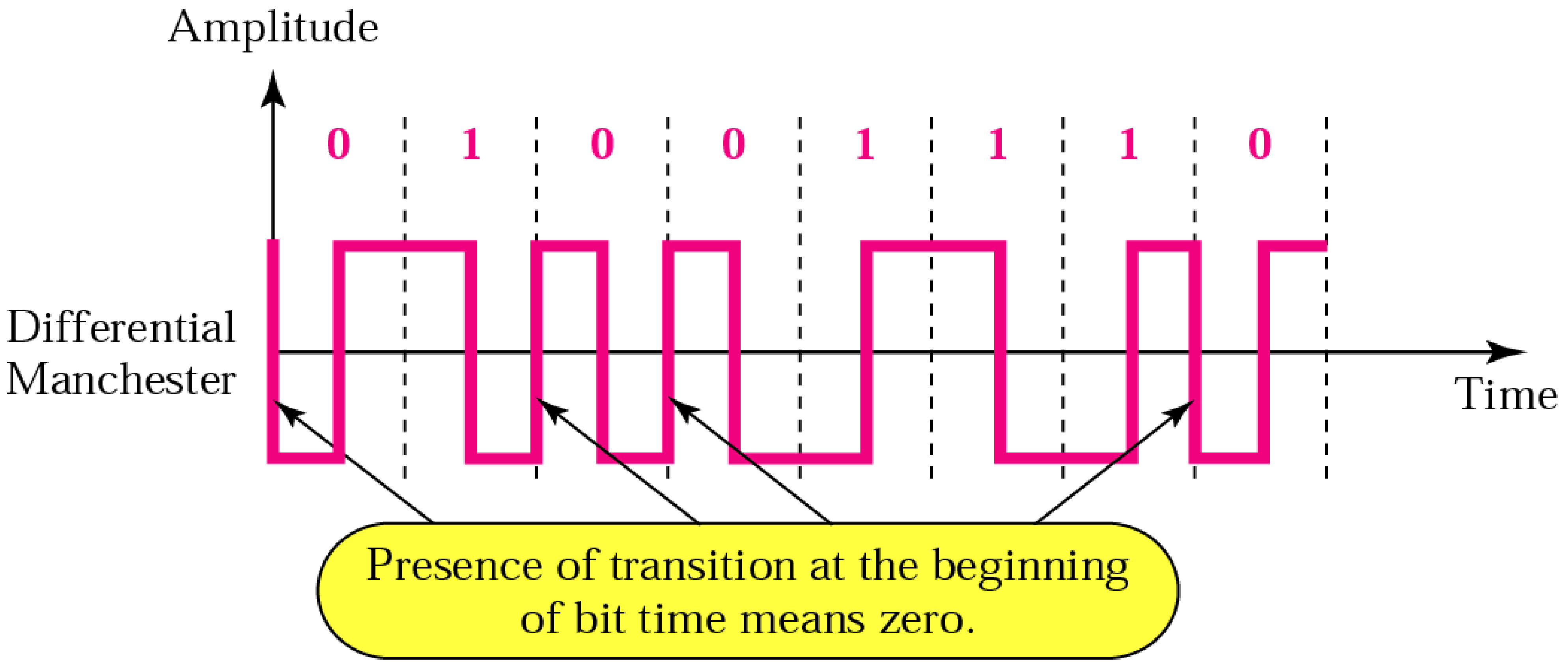
- No DC Component
- No problem with long runs of 1s or 0s
- Wastage of bandwidth for a multilevel scheme
- Requires higher signal power for same BER

Manchester



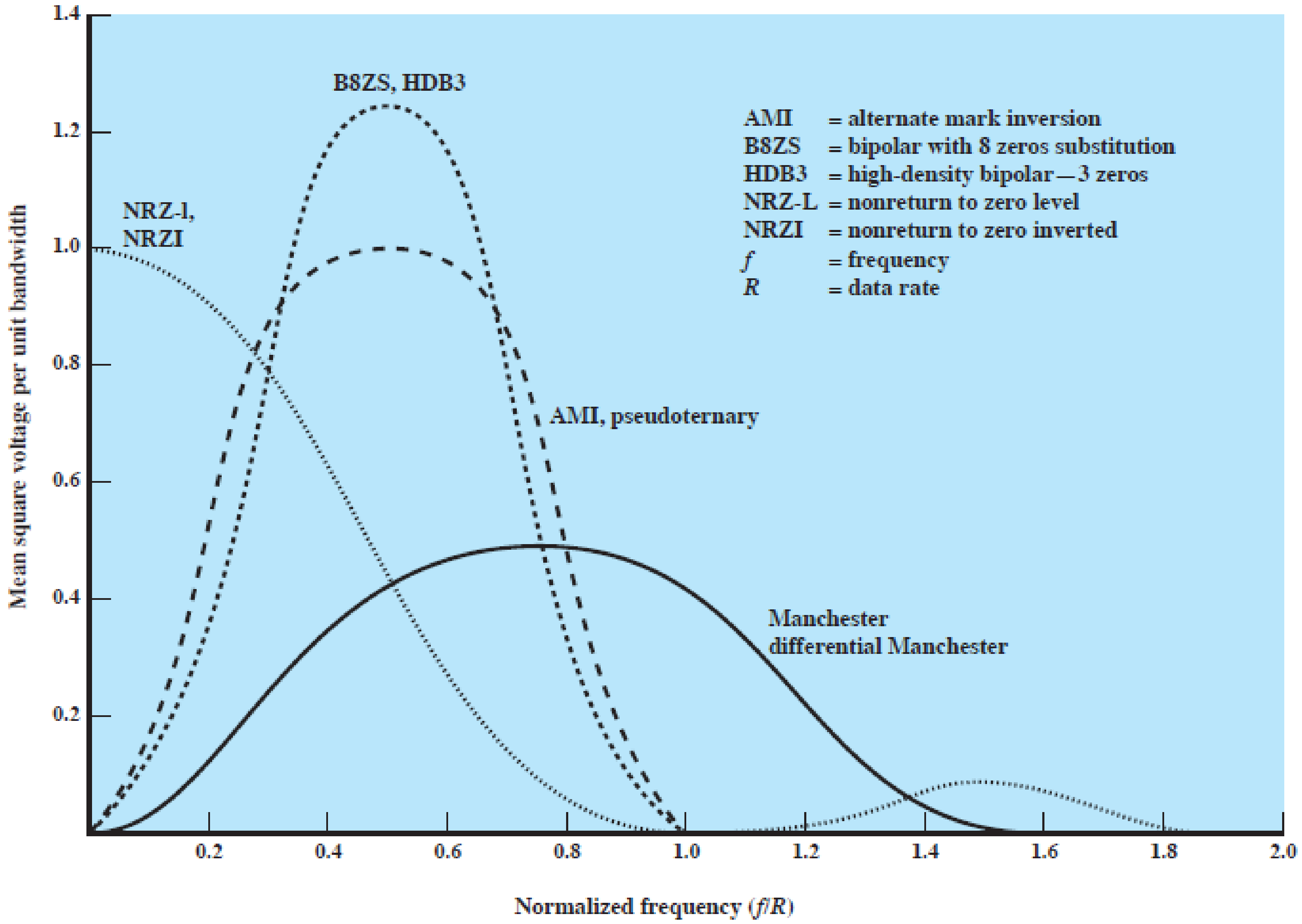
- Transition for clocking and bit representation
- No DC component
- Noise has to invert signal before and after midpoint
- Requires higher bandwidth than other bipolar schemes

Differential Manchester



- Transition at the beginning of bit period represents 0
- Another differential encoding scheme
- Two transitions per bit in the worst case
- Requires twice bandwidth of bitrate

Bandwidth comparison



Scrambling

- Use scrambling to replace sequences that would produce constant voltage
- Filling sequence
  — Must produce enough transitions to sync
  — Must be recognized by receiver and replace with original
  — Same length as original
- No dc component
- No reduction in data rate
- Error detection capability

Block coding

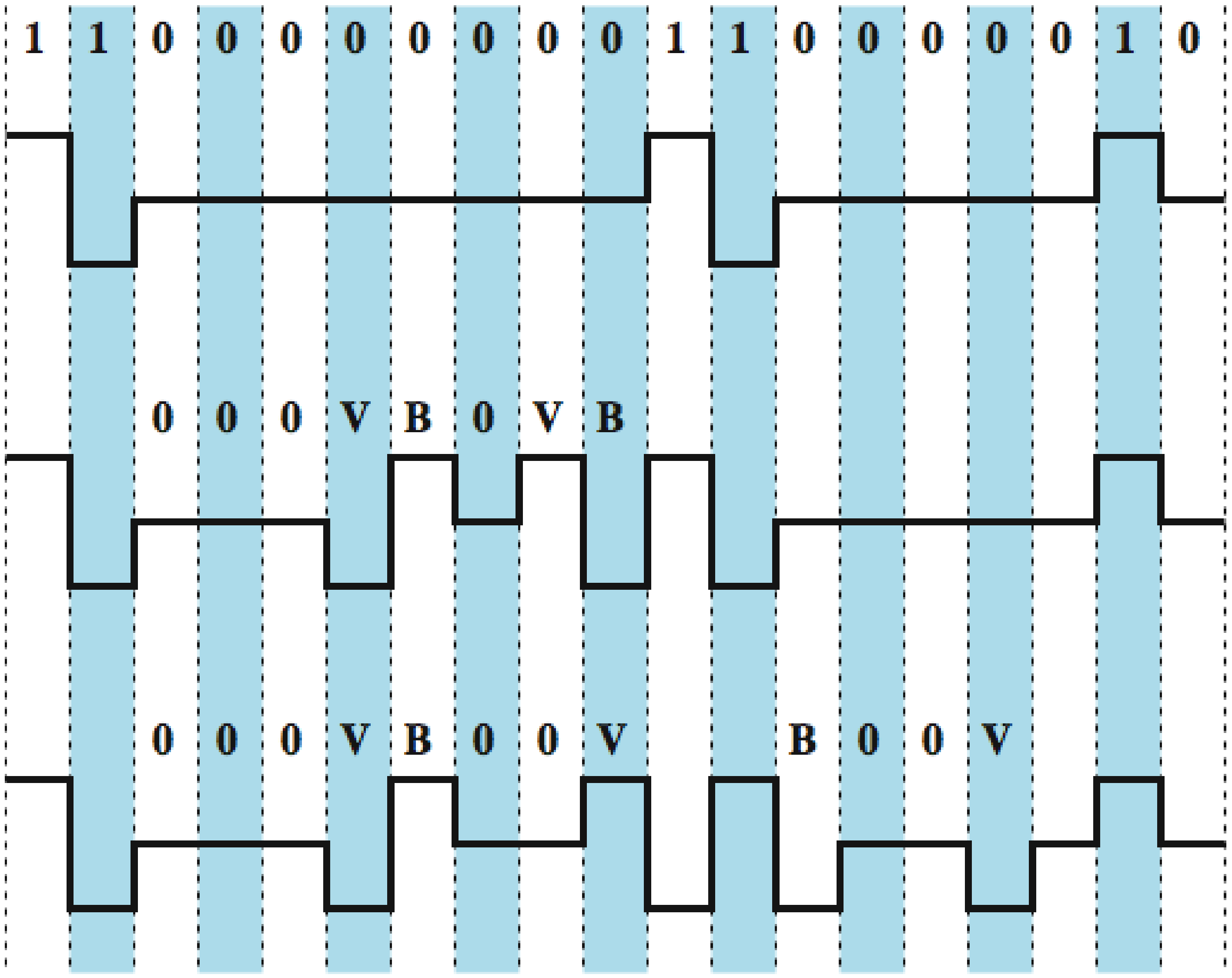
- Handling synchronization issues for schemes with lower bandwidth
- NRZ-I has problem with string of 0s
- Eliminate consecutive 0s by encoding block with another one
- mB/nB: replace m bits with n bits
- Can be used for error detection also
- Increases the bitrate and introduces delay in encoding
- Does not solve DC component issue
- Solution is to use Scrambling for long distance communication

B8ZS

Any run of 4 zeros is replaced by the special pattern: B00X

- X is sent as +/- , such that successive X's have alternating polarity (1st X is arbitrary)
- B is sent as 0 or +/- . Select B such that the next X violates the AMI alternating polarity result,

  i.e send B as 0 if X violates the polarity rule. Otherwise send B=X to force a violation of the alternating polarity rule

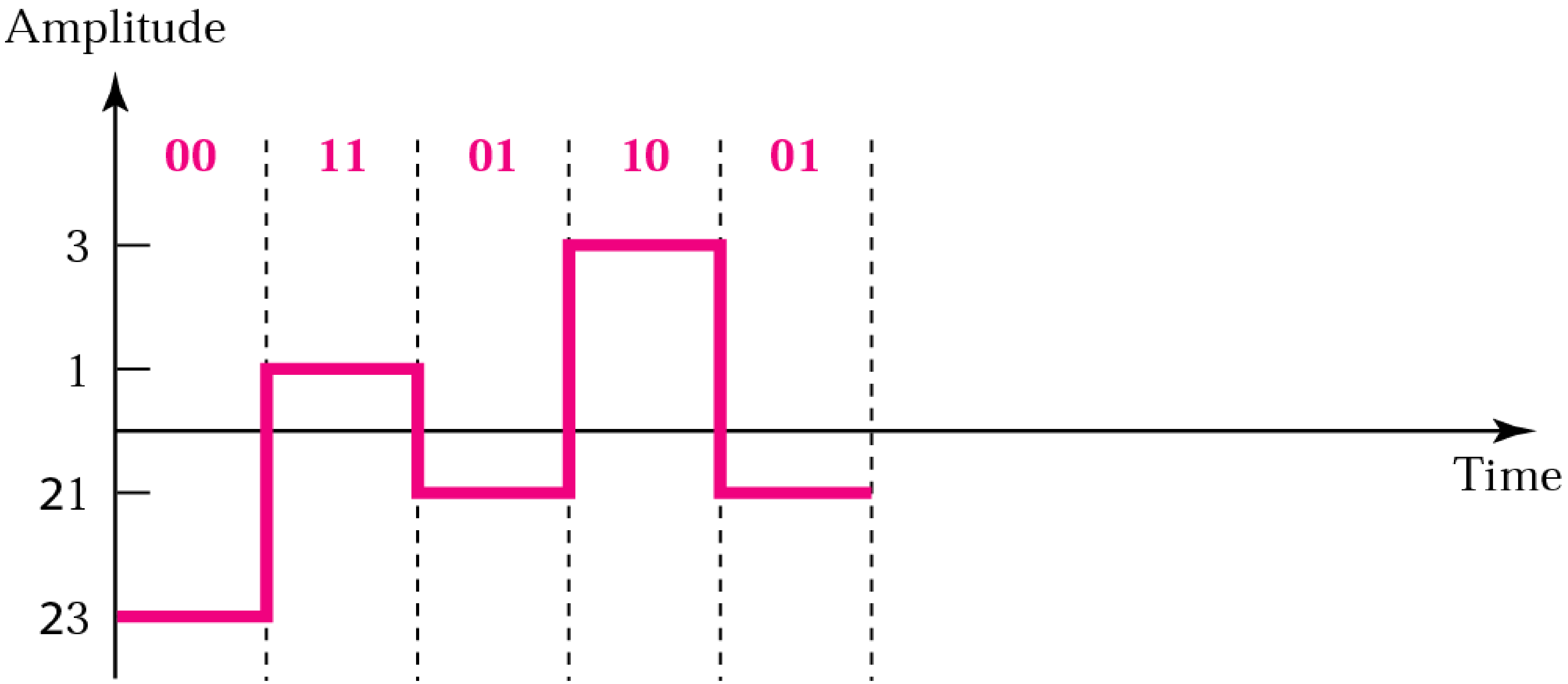


Valid bipolar signal
Bipolar violation

Multi-level schemes

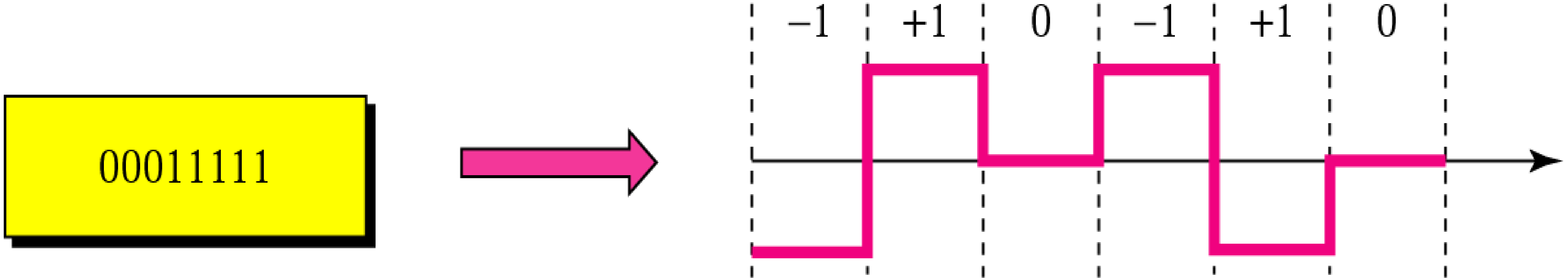
- Increase number of bits per baud
- 2^m data elements on L^n signal patterns; often expressed as mBnL
- Mostly $2^m \le L^n$;
- Redundancy used for synchronization, error detection, DC balance
- Average baud rate is n/m * B/2.
- Combined with parallel transmission to get high data rates
- Complex coding tables

2B1Q



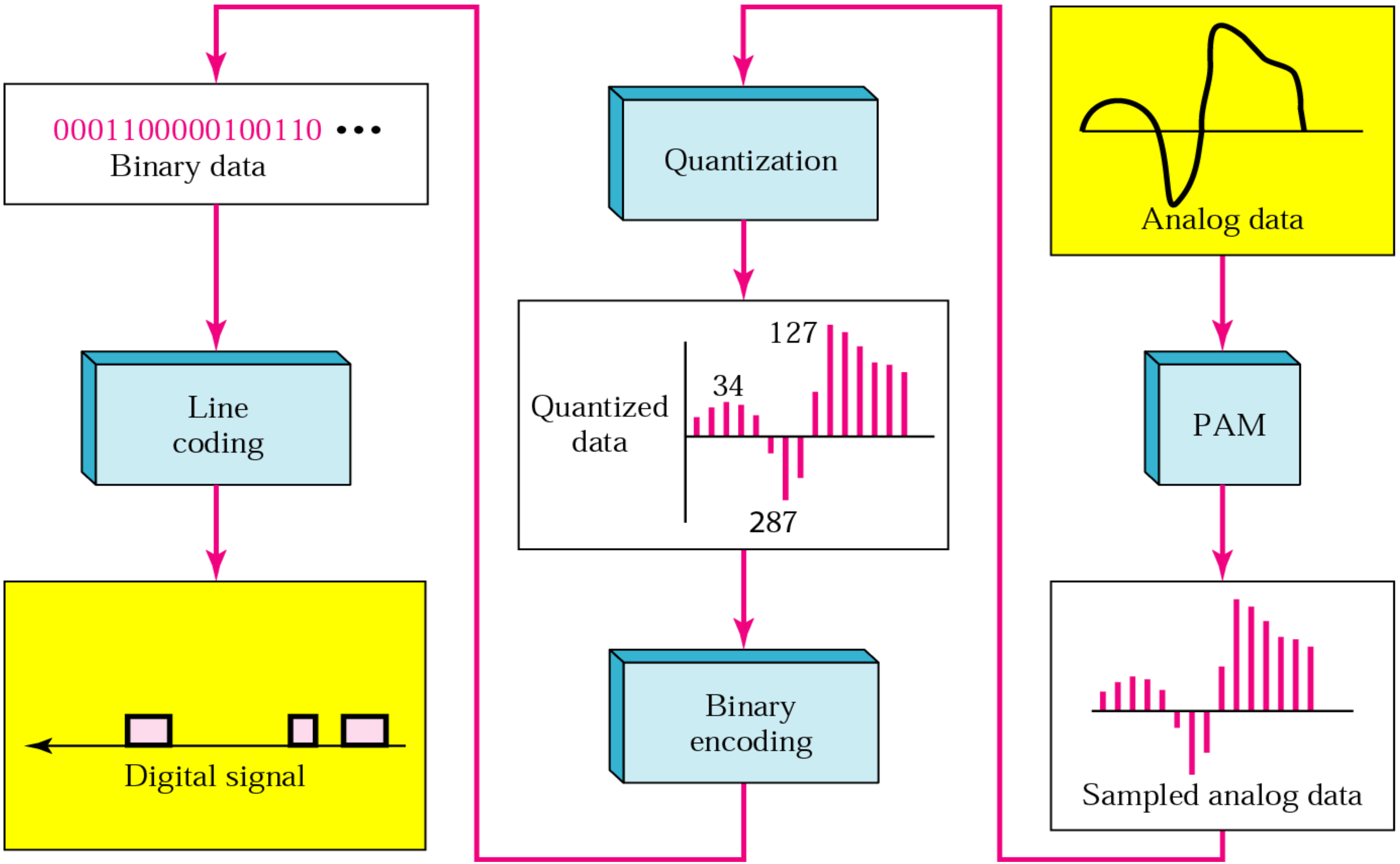
- No redundancy available
- Used in DSL
- Transition table defines the coding scheme
- Requires half bandwidth compared to NRZ-L

8B6T



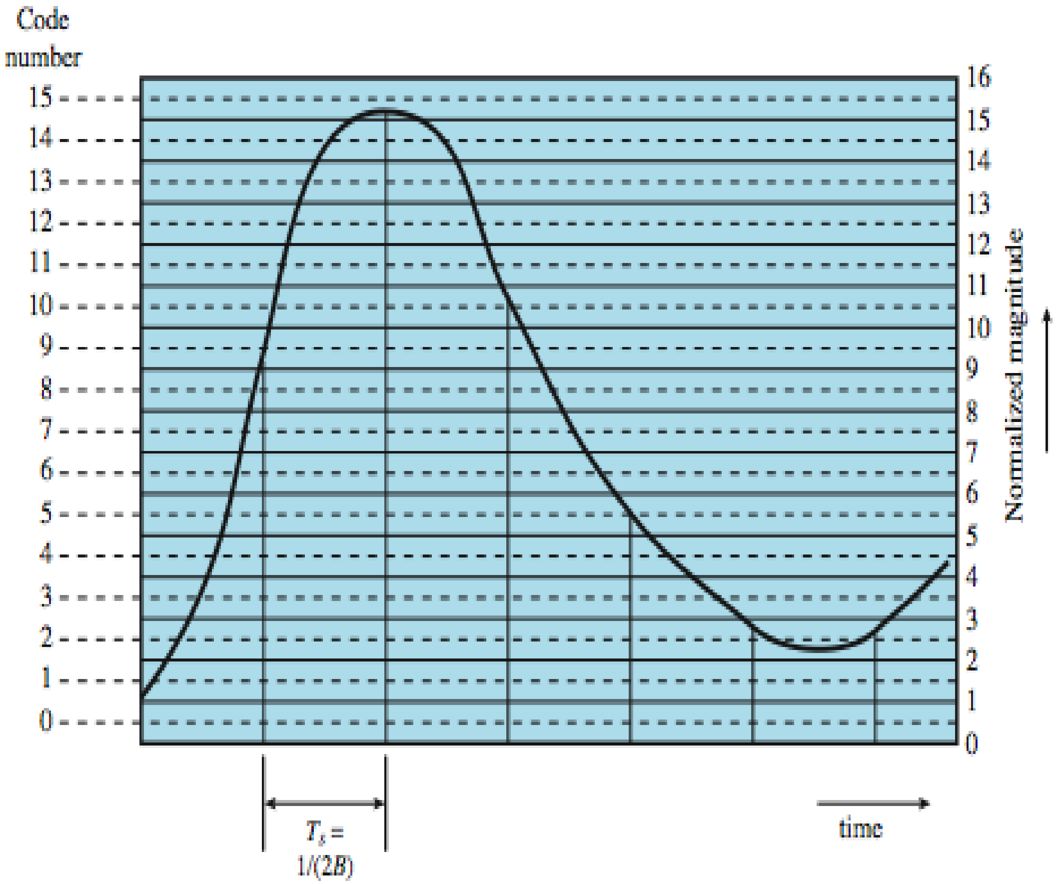
- 256 bit patterns encoded with 478 signal elements
- Redundancy used for DC balance, synchronization, error detection
- Sender keeps track of weight; signal always has 0 or +1 weight
- Pattern inverted before transmission to produce -1 weight
- Synchronization patterns are introduced during transmission
- 8B4Q sent using 4 parallel lines each with 125Mbaud capacity in 1Gbps LAN

Overview of Analog to Digital Conversion



Pulse Code Modulation (PCM)

- Nyquist Sampling Rate
  - Uniform sampling rate twice the highest frequency is enough
- Pulse amplitude modulation signal
- Discretized by quantization
- Coded in m-digits
- Quantization error or noise
  - Depends on V and m
- SNR = 6.02m+1.76 dB

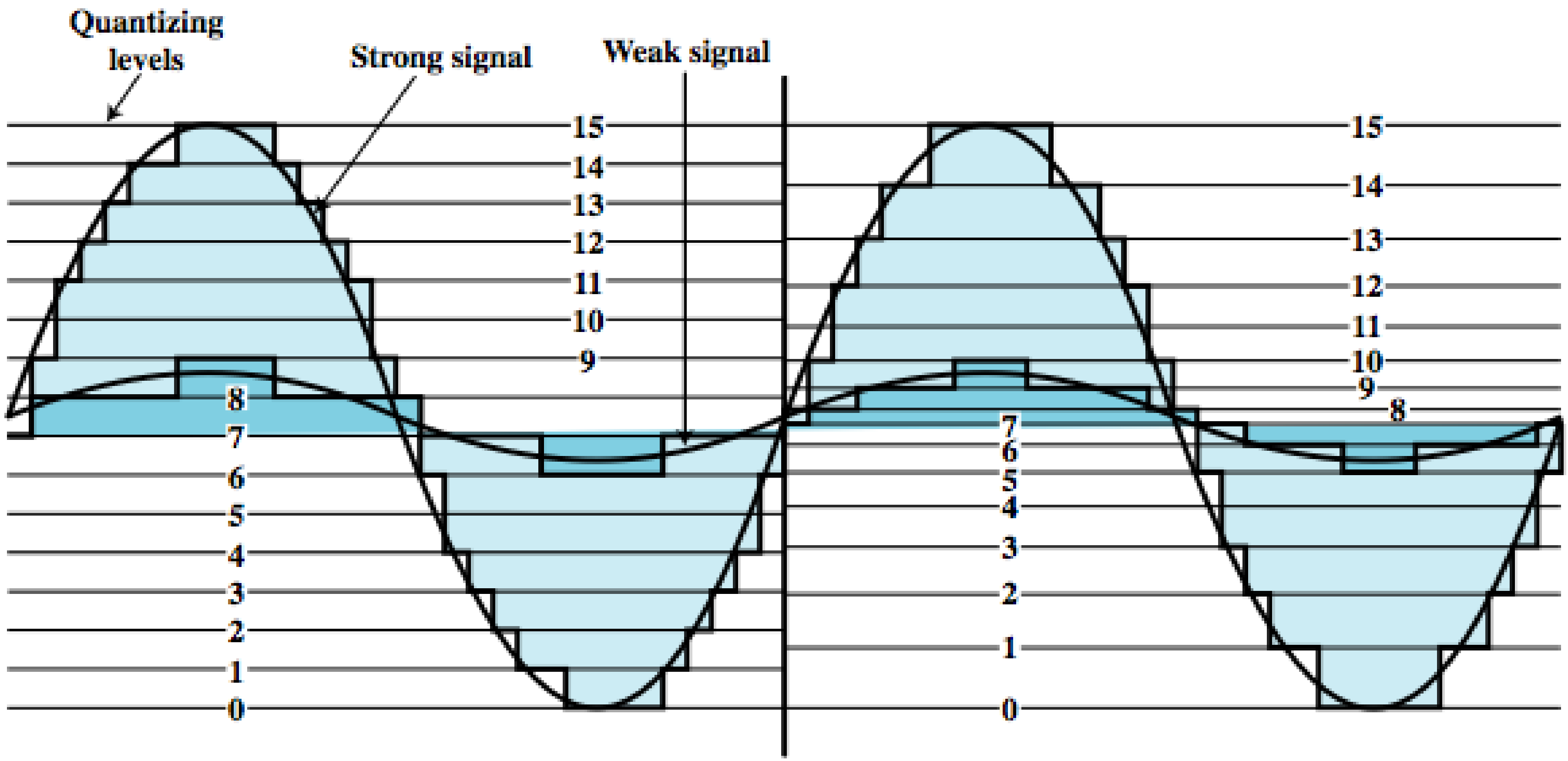


PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

Non-linear coding

- Equal spacing of levels produce same mean error for any signal value
- Lower signal values are more distorted
- More levels near low amplitude values – non-linear spacing
- Alternately, companding (compress-expand) the input signal
    - Impart higher gain to weaker signal values
    - Higher values are reduced relative to the lower values

Non-linear coding



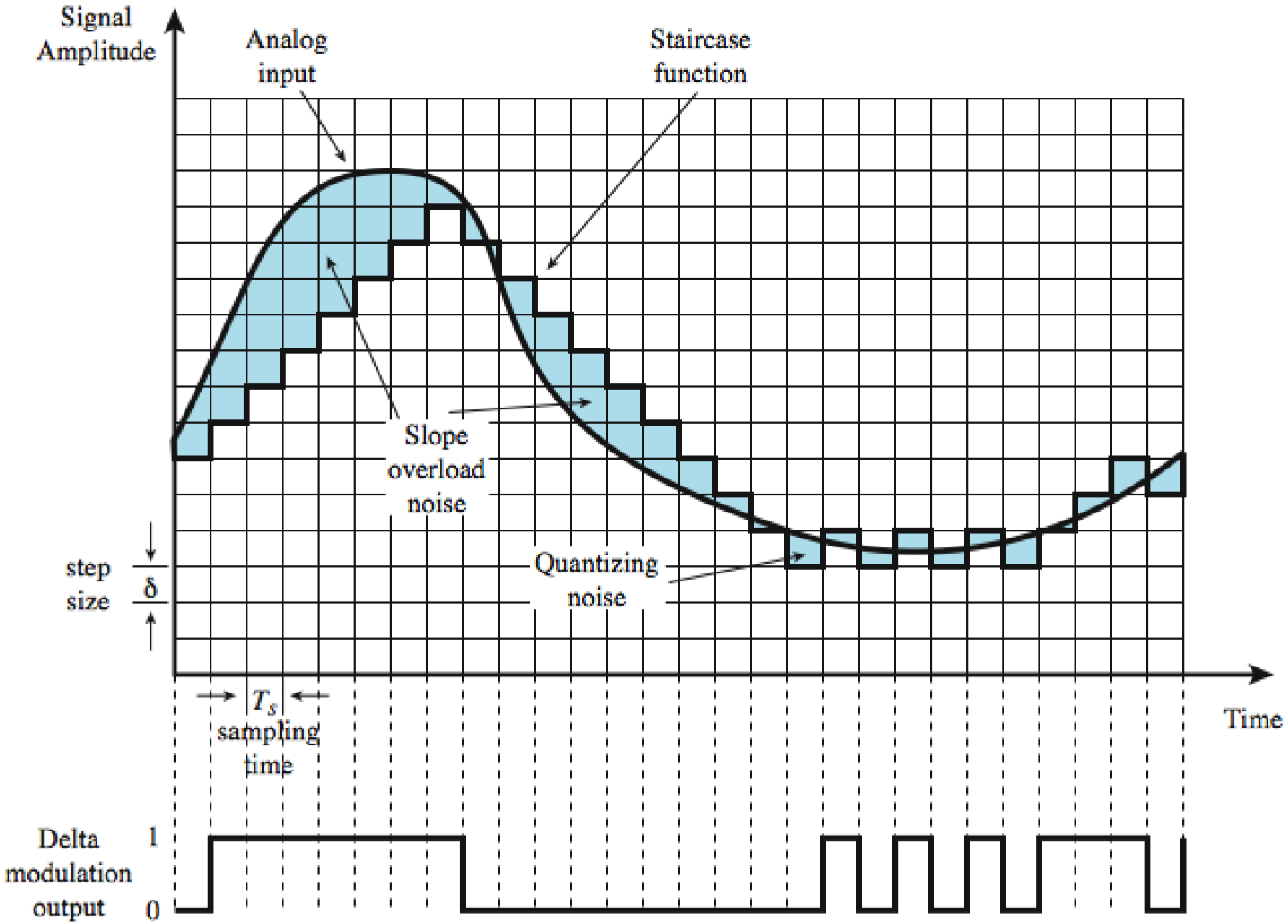
(a) Without nonlinear encoding

(b) With nonlinear encoding

Delta Modulation

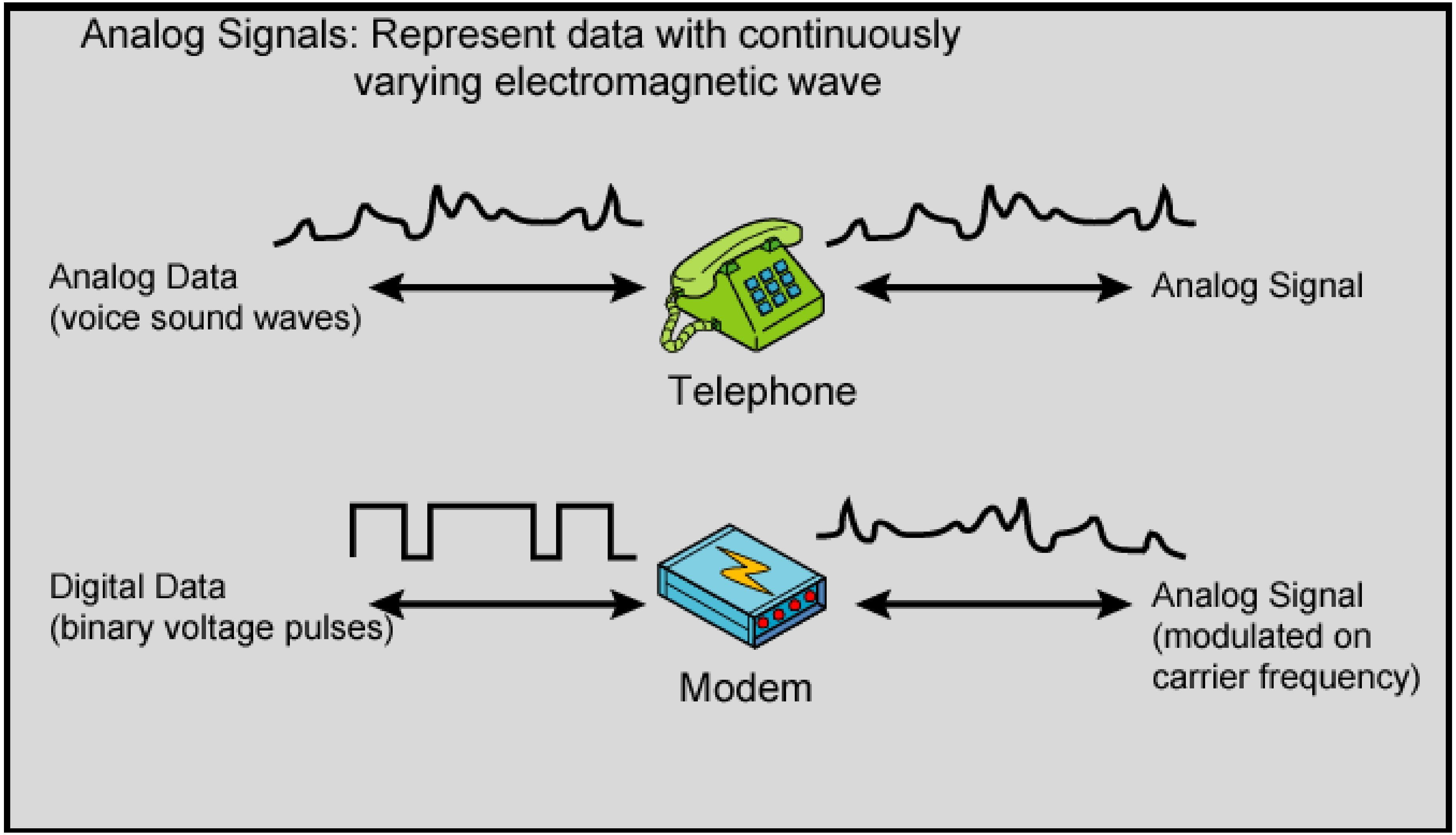
- Analog input is approximated by a staircase function
  - can move up or down one level (δ) at each sample interval
  - has binary behavior, hence can encode each sample as single bit
  - 1 for up or 0 for down
- DM has simplicity compared to PCM
- but has worse SNR

Delta Modulation



Analog Transmission

Analog Signals

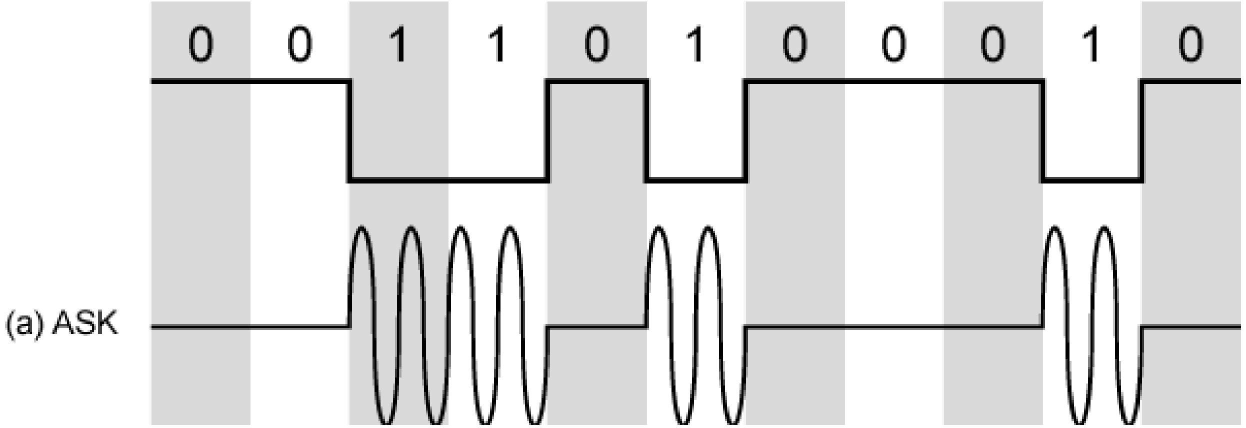


Modulation of Carrier Amp., Freq., or Phase

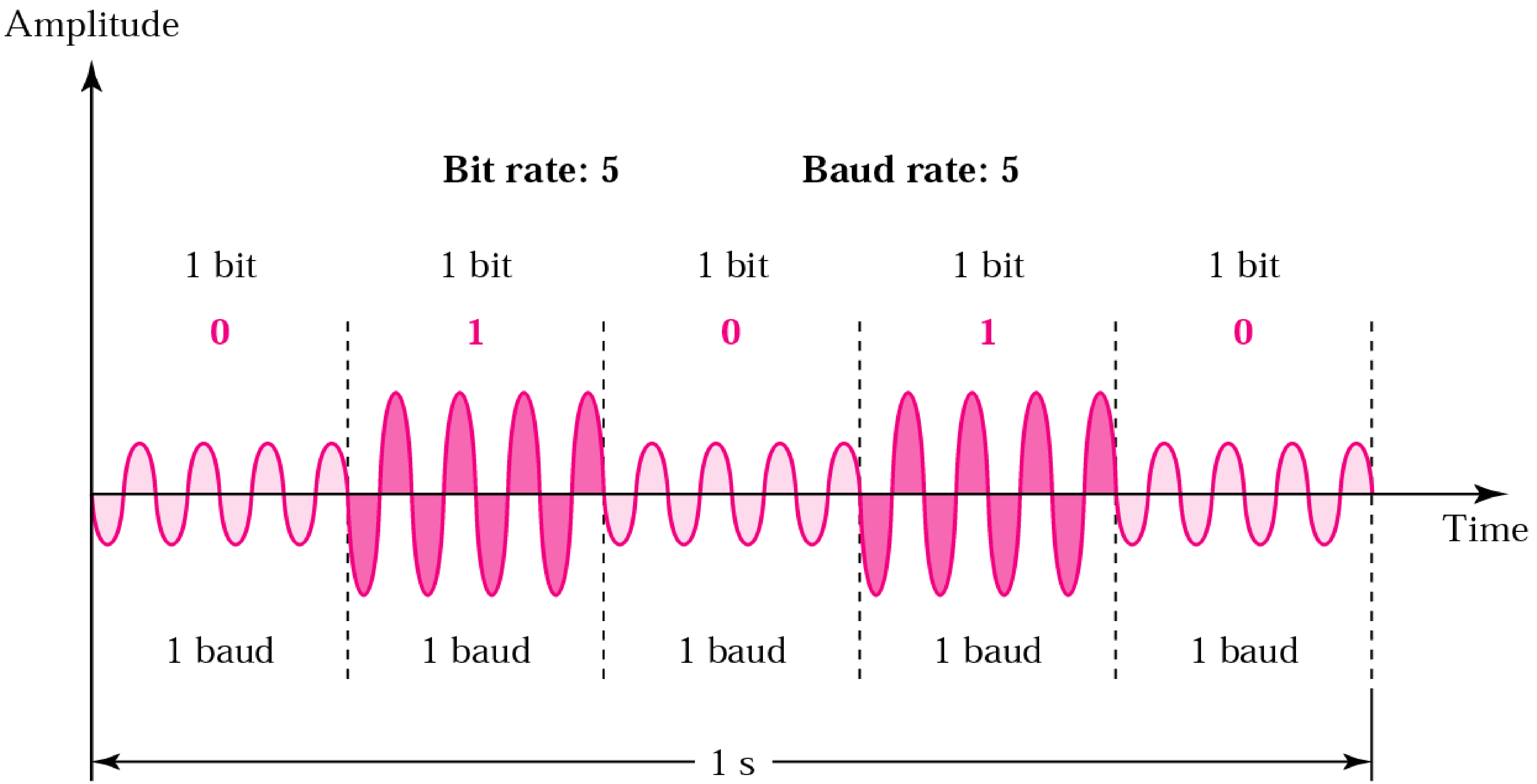
Modulation with digital signal

Amplitude Shift Keying

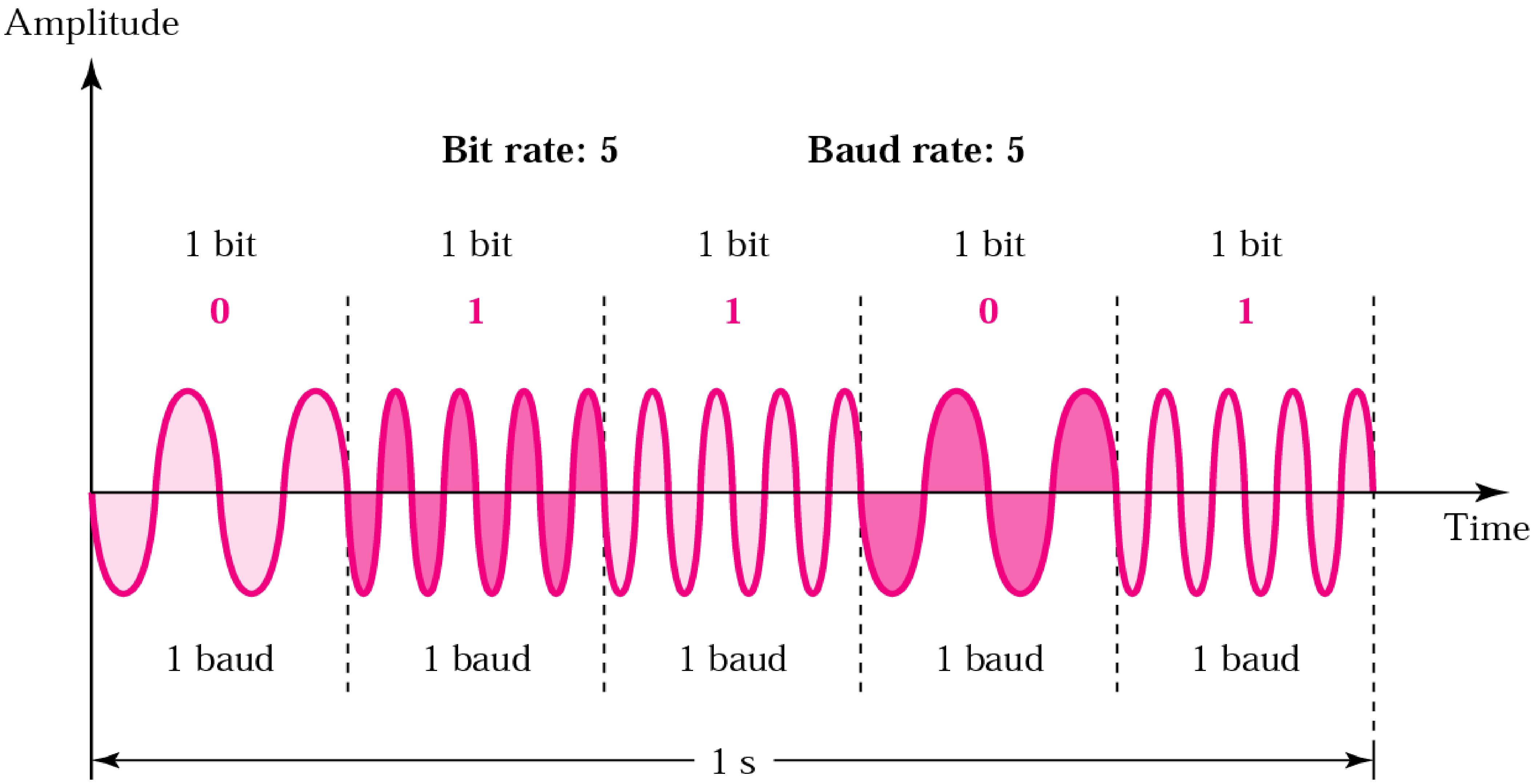
- encode 0/1 by different carrier amplitudes
  - usually have one amplitude zero
- susceptible to sudden gain changes
- inefficient
- used for
  - up to 1200bps on voice grade lines
  - very high speeds over optical fiber



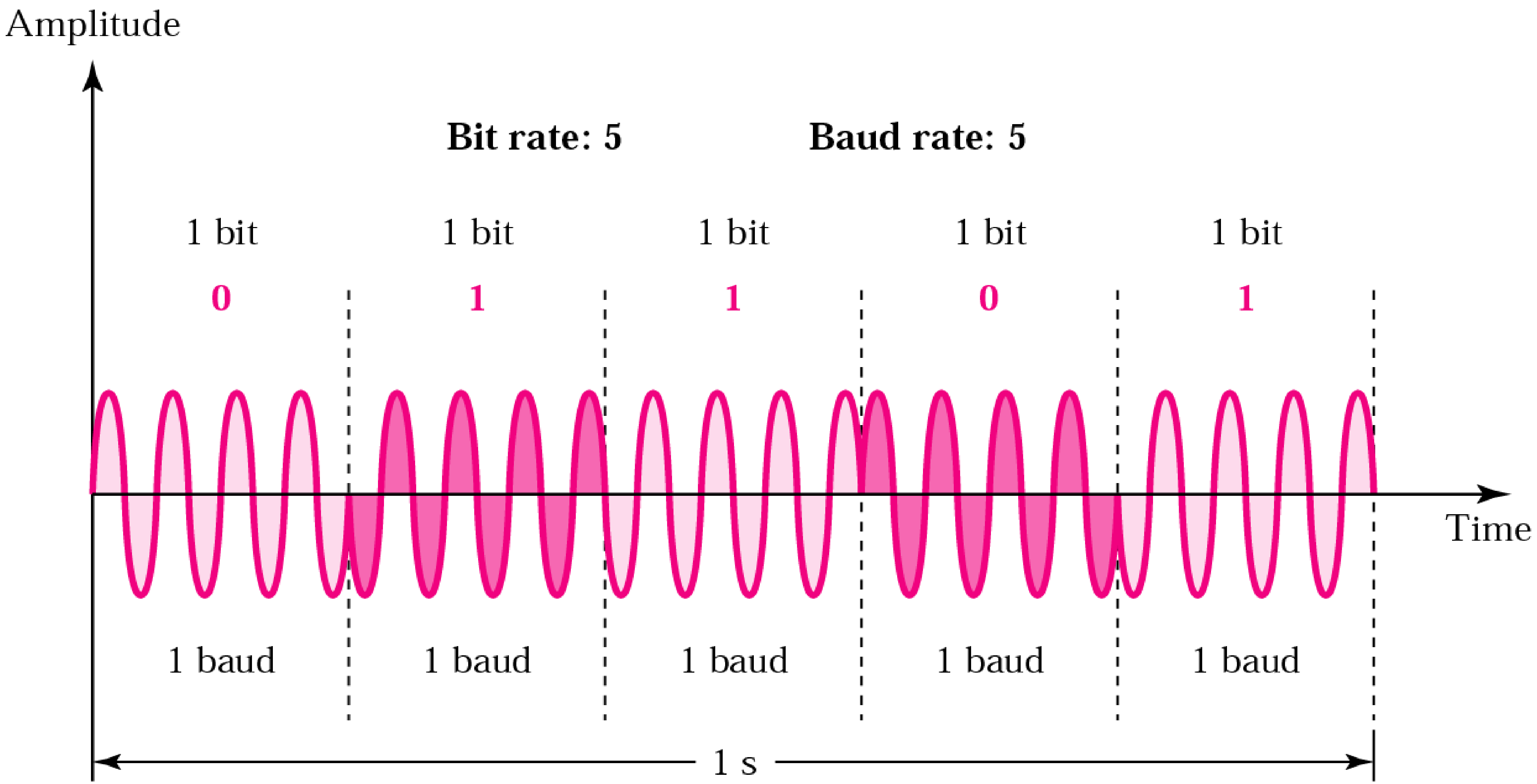
Amplitude Shift Keying



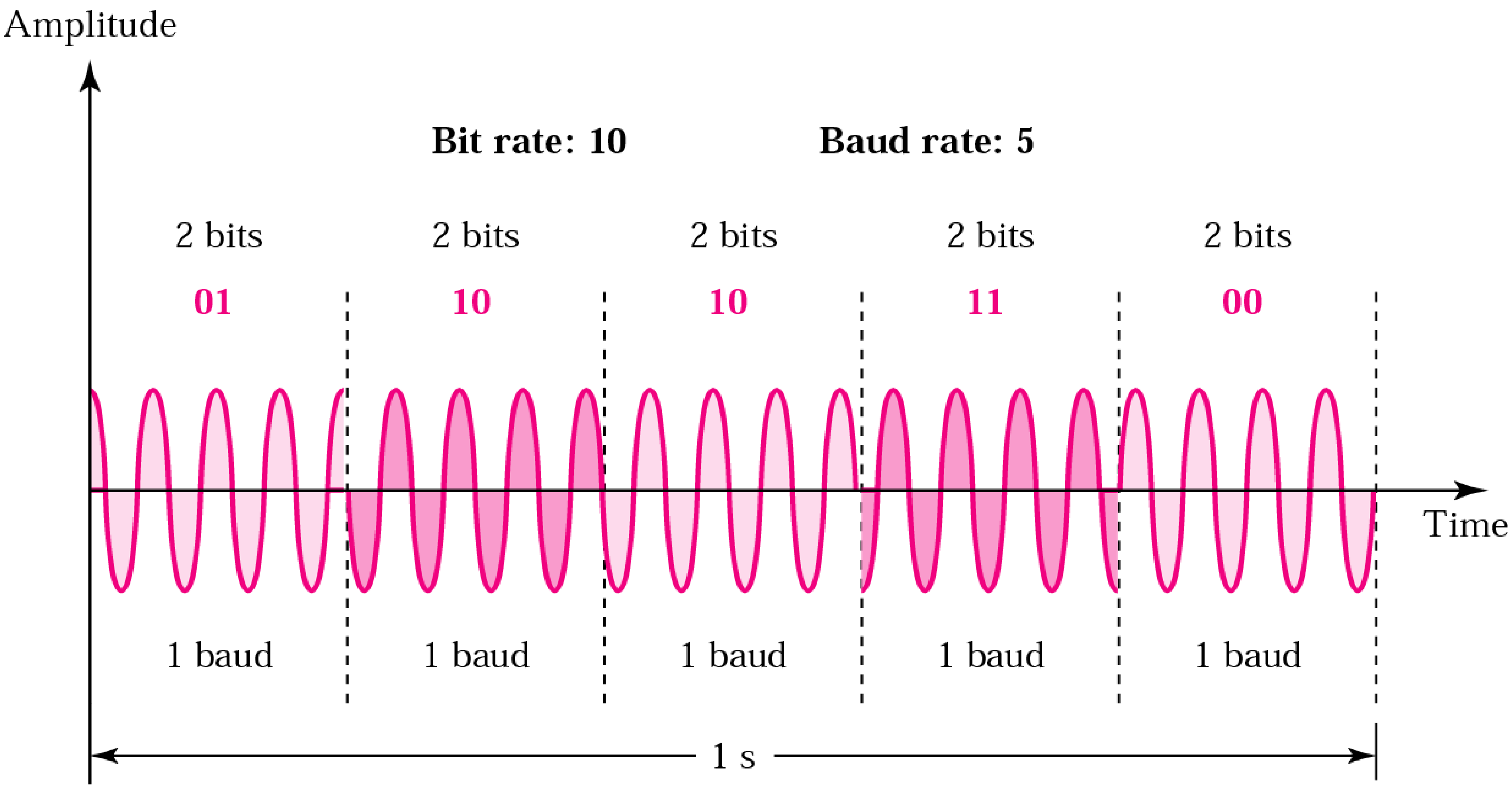
Frequency Shift Keying



Phase Shift Keying

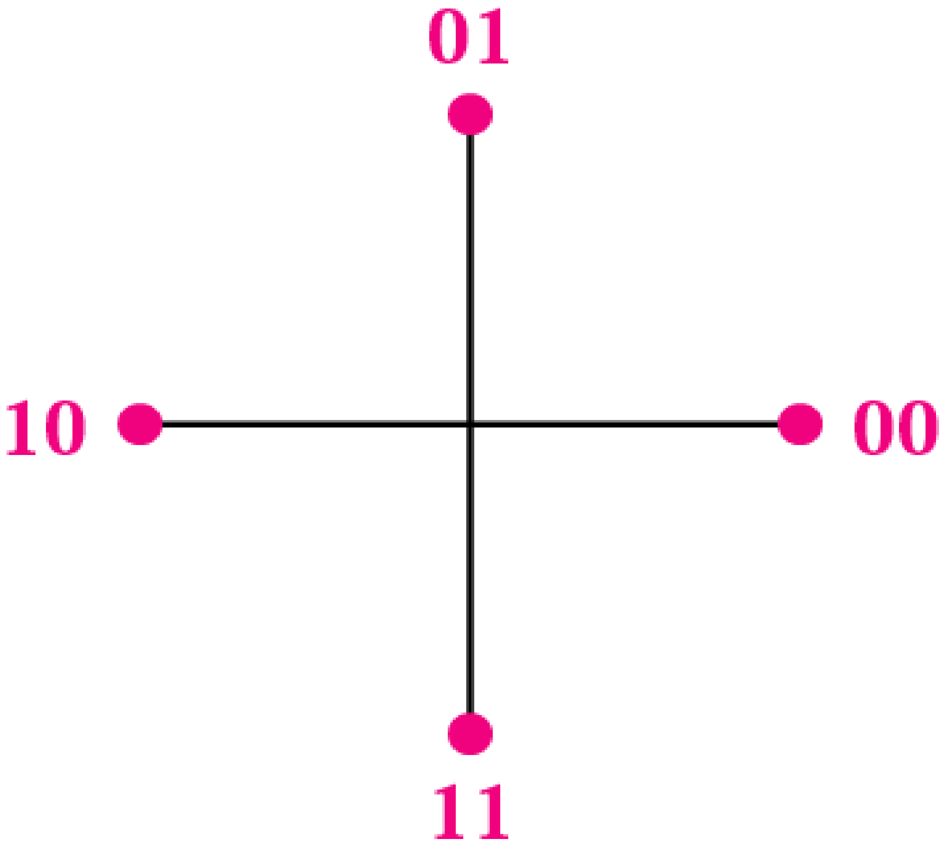


Quadrature Phase Shift Keying



Dibit	Phase
00	0
01	90
10	180
11	270

Dibit
(2 bits)

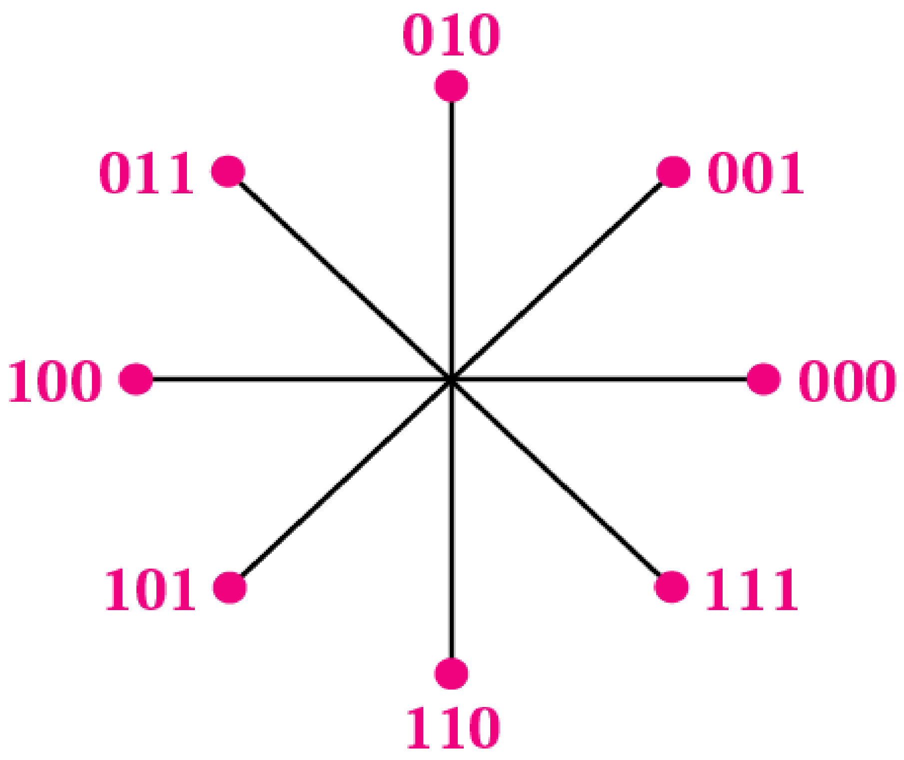


Constellation diagram

8-level Phase Shift Keying

Tribit	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

Tribits
(3 bits)

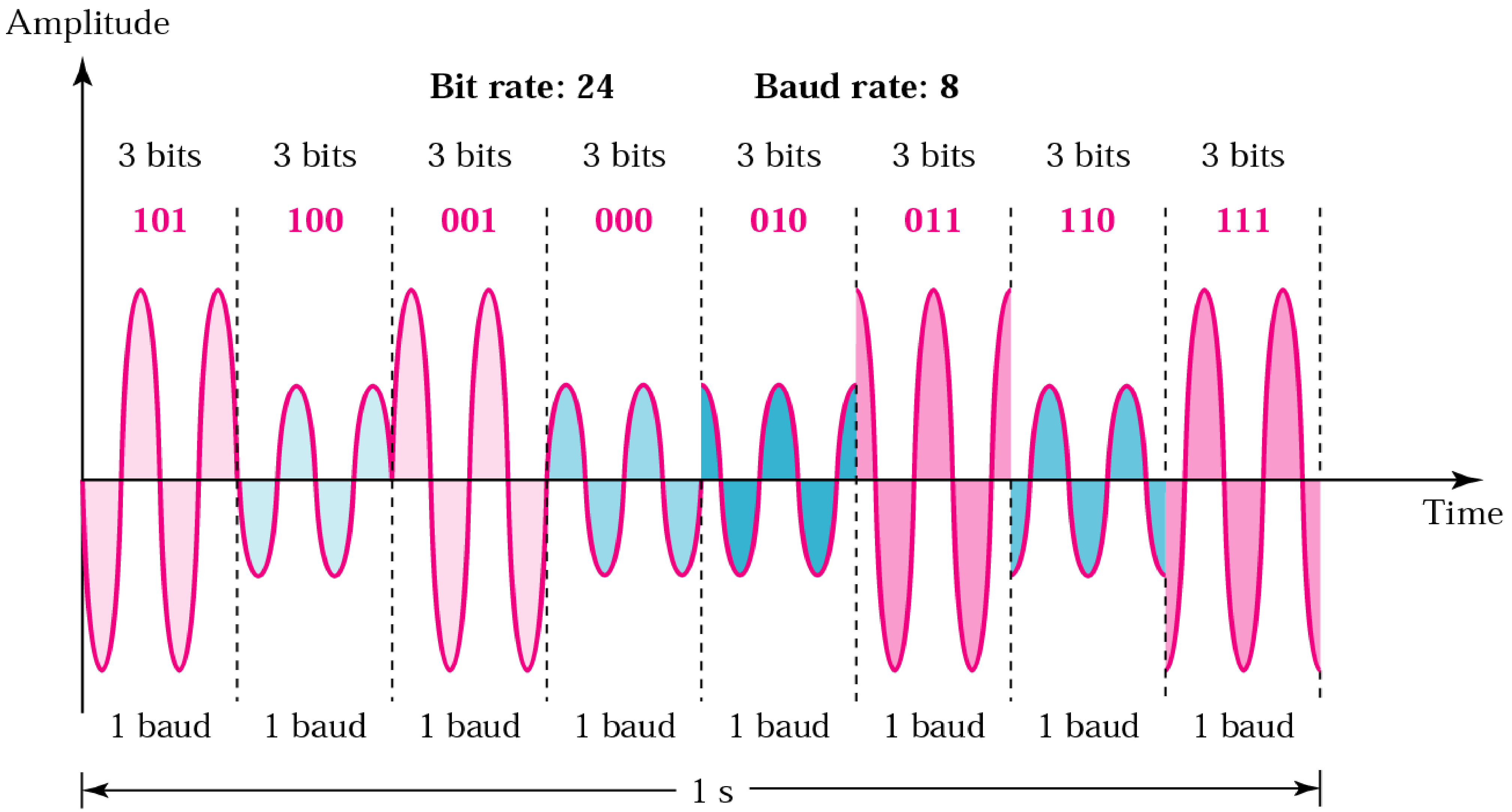


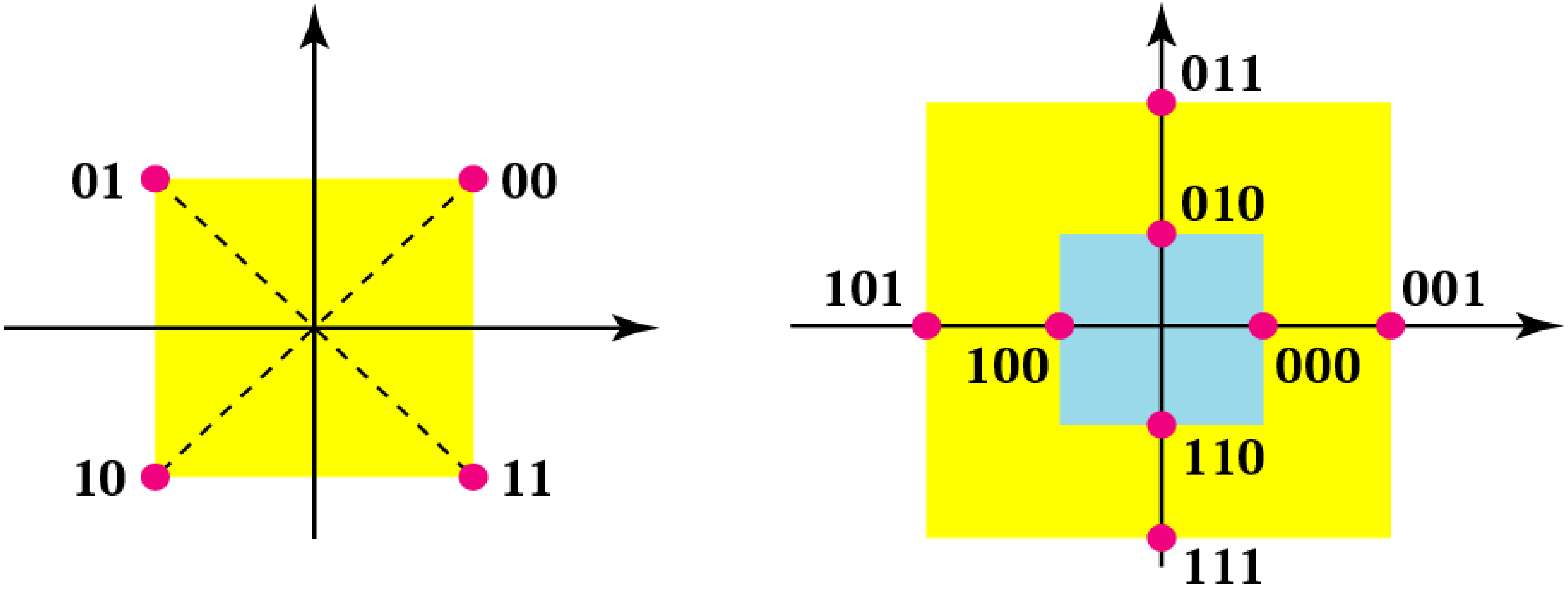
Constellation diagram

Quadrature Amplitude Modulation

- QAM used on asymmetric digital subscriber line (ADSL) and some wireless
- combination of ASK and PSK
- logical extension of QPSK
- send two different signals simultaneously on same carrier frequency
  - use two copies of carrier, one shifted 90°
  - each carrier is ASK modulated
  - two independent signals over same medium
  - demodulate and combine for original binary output

8-QAM


Amplitude
Bit rate: 24
Baud rate: 8
3 bits
101
100
001
000
010
011
110
111
Time
1 baud
1 s

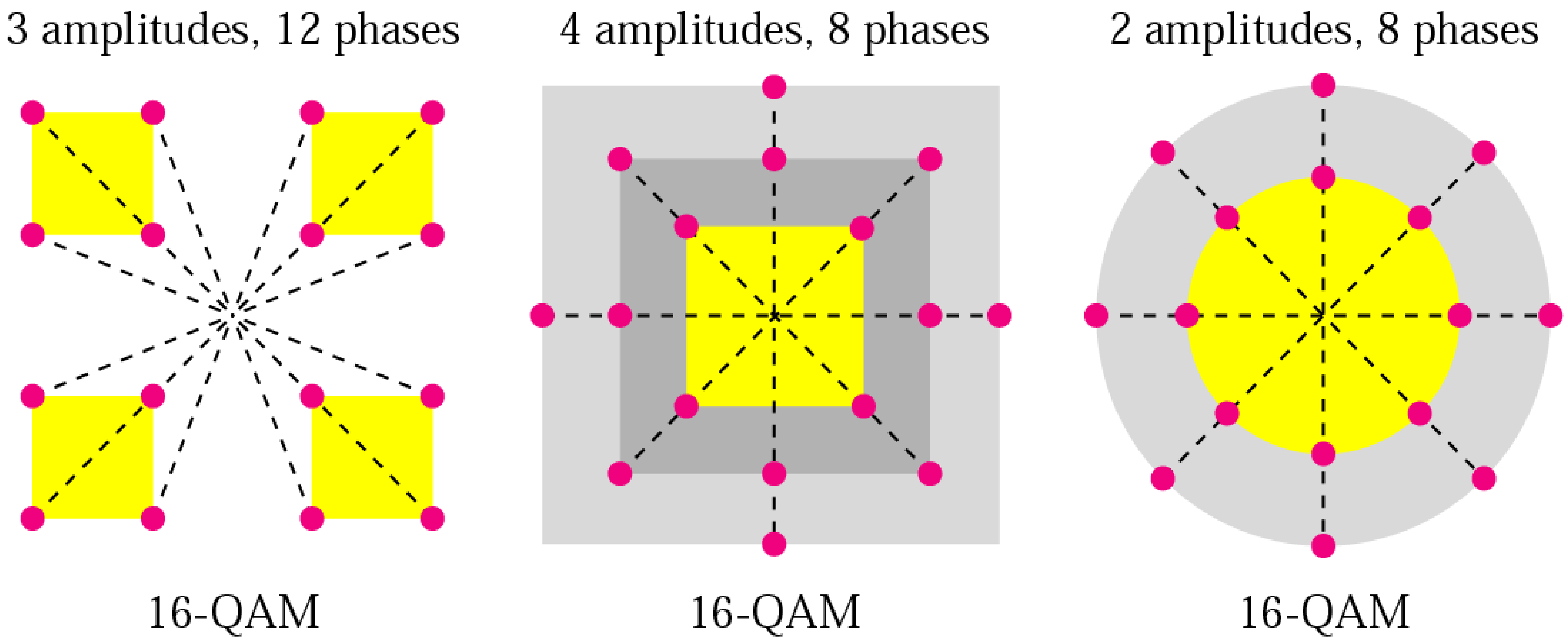


4-QAM
1 amplitude, 4 phases

8-QAM
2 amplitudes, 4 phases

QAM Variants

- two level ASK
  - each of two streams in one of two states
  - four state system
  - essentially QPSK
- four level ASK
  - combined stream in one of 16 states
- have 64 and 256 state systems
- improved data rate for given bandwidth
  - but increased potential error rate


3 amplitudes, 12 phases
4 amplitudes, 8 phases
2 amplitudes, 8 phases
16-QAM
16-QAM
16-QAM