

Digital Transmission

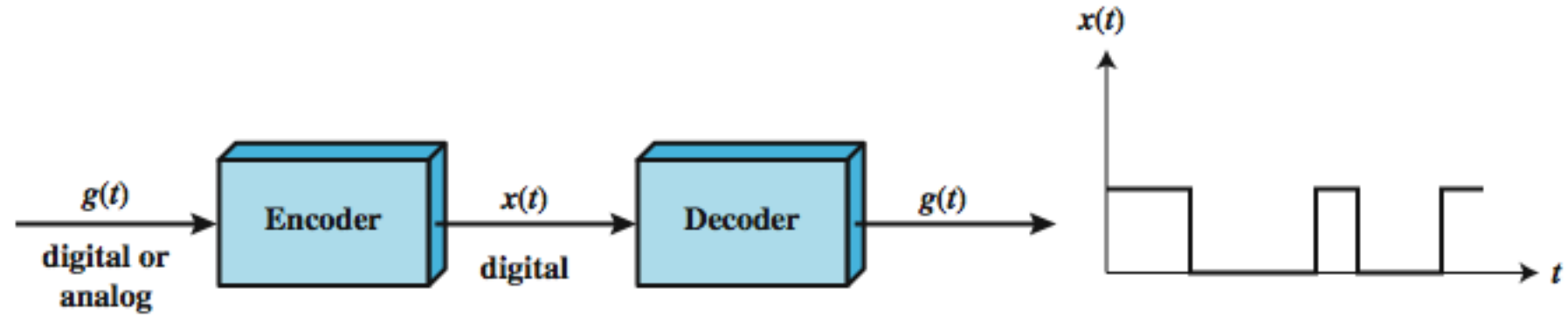
Channel capacity

- Max. data rate over a transmission system under given conditions
- Relate data rate, bandwidth, noise, bit error rate
- Nyquist rate (ideal noiseless lowpass channel)
 - If rate of signal transmission is $2B$, then signal with frequency no greater than B is sufficient to carry the information
 - Noiseless channel, only limitation due to ISI from delay distortion
 - $C = 2B \log_2 M$
- Shannon capacity (ideal lowpass channel)
 - Given SNR at the receiver, the maximum data rate over a channel with bandwidth B is $C = B \log_2(1 + \text{SNR}_{\text{dB}})$
 - Assumes only white noise, practical capacity is much lower
- As B increases SNR decreases
- As signal power increases, nonlinear effects increase

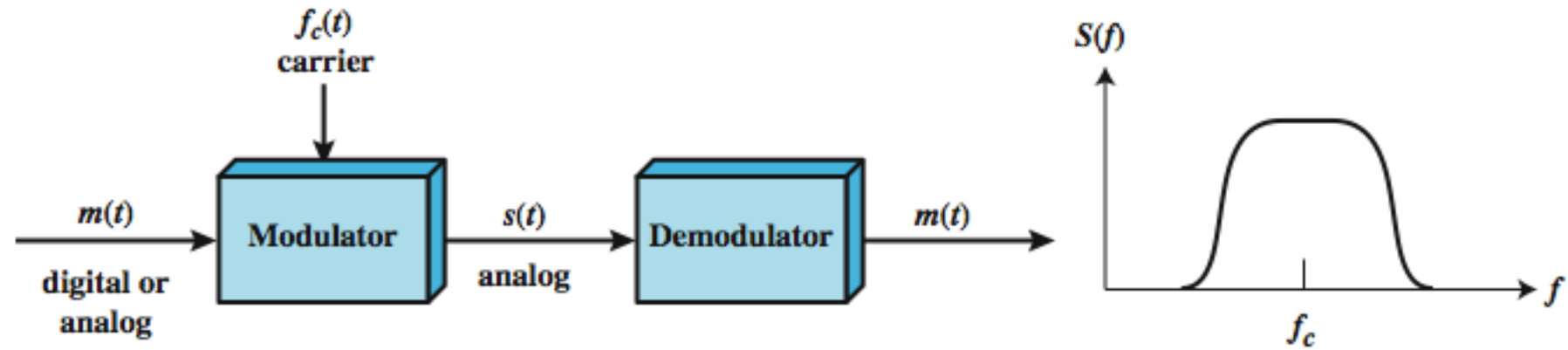
Channel Capacity

- 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.

Data and Signals



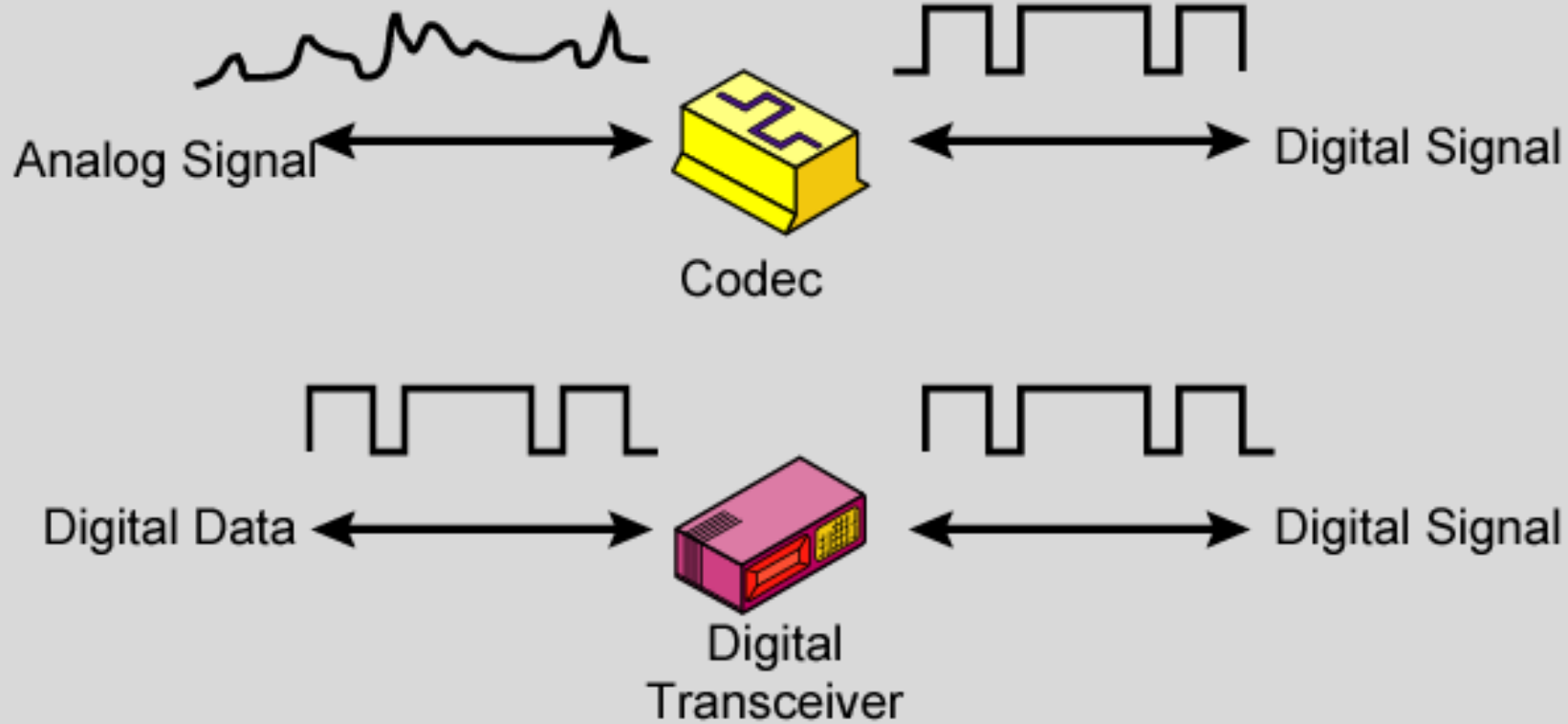
(a) Encoding onto a digital signal



(b) Modulation onto an analog signal

Digital Signals

Digital Signals: Represent data with sequence of voltage pulses



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)

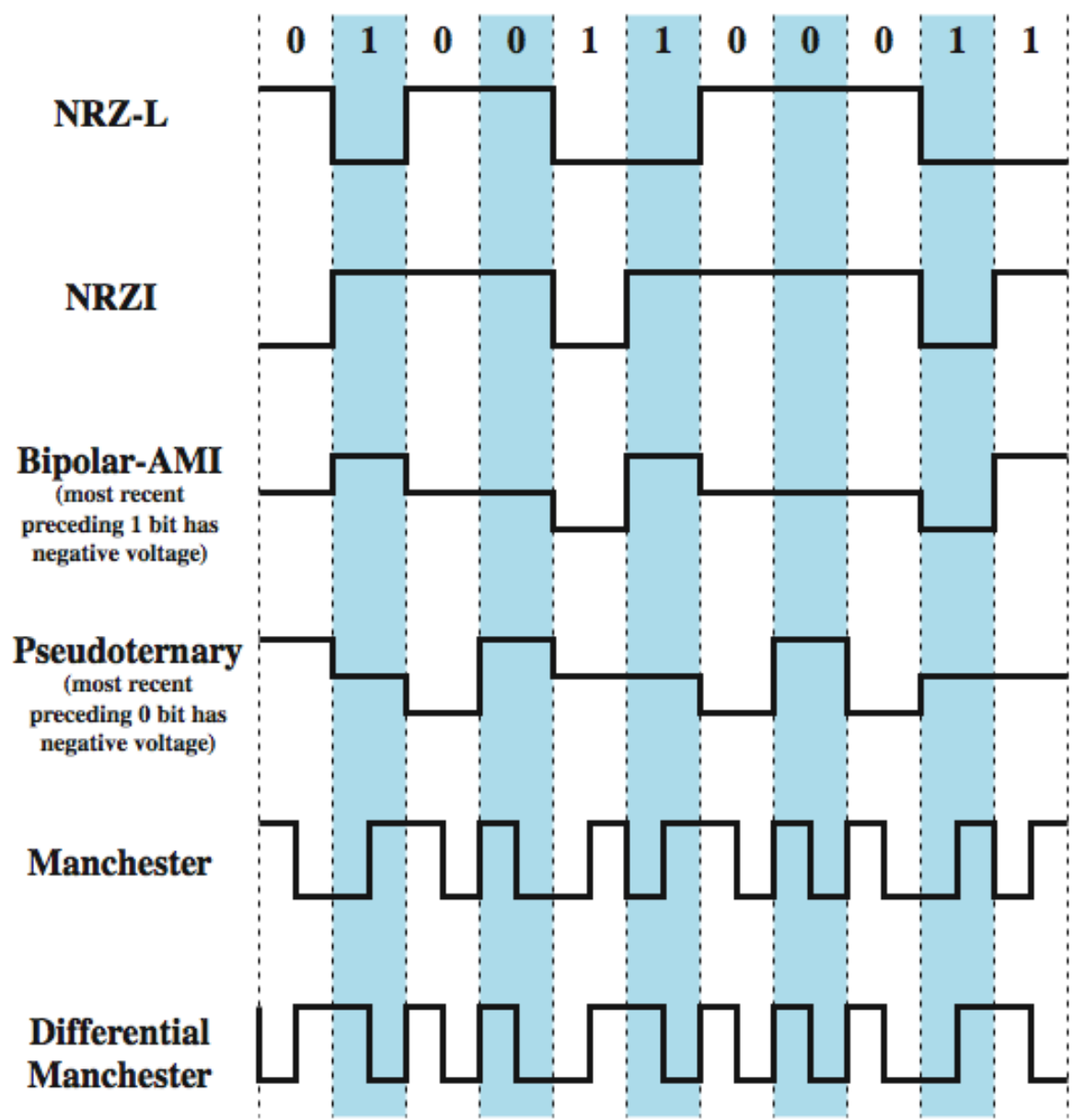
Digital Signal Properties

- 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

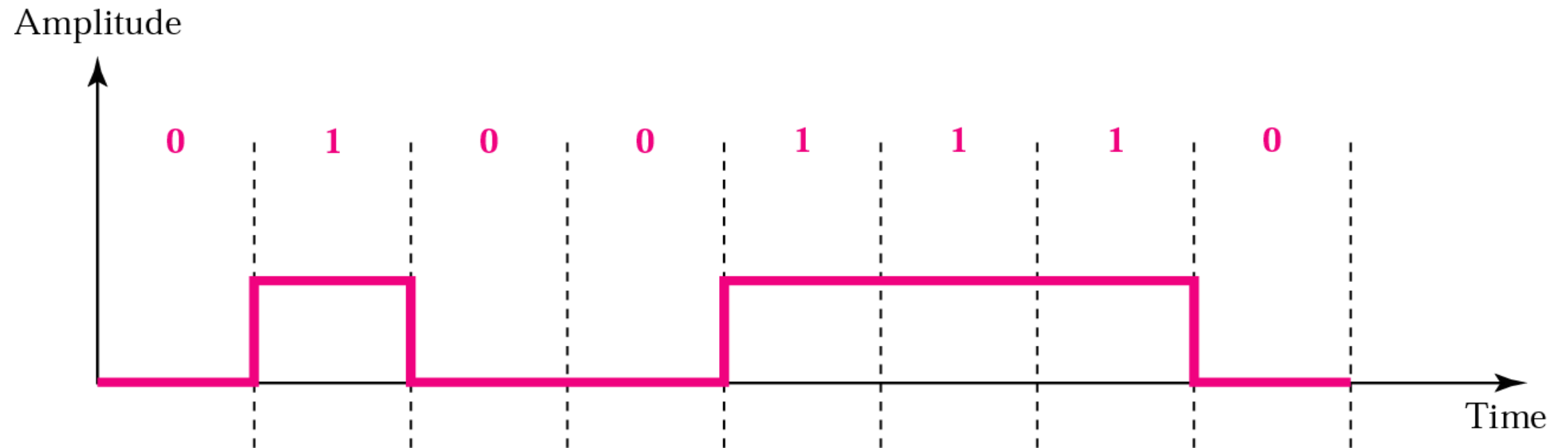
Encoding Considerations

- 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

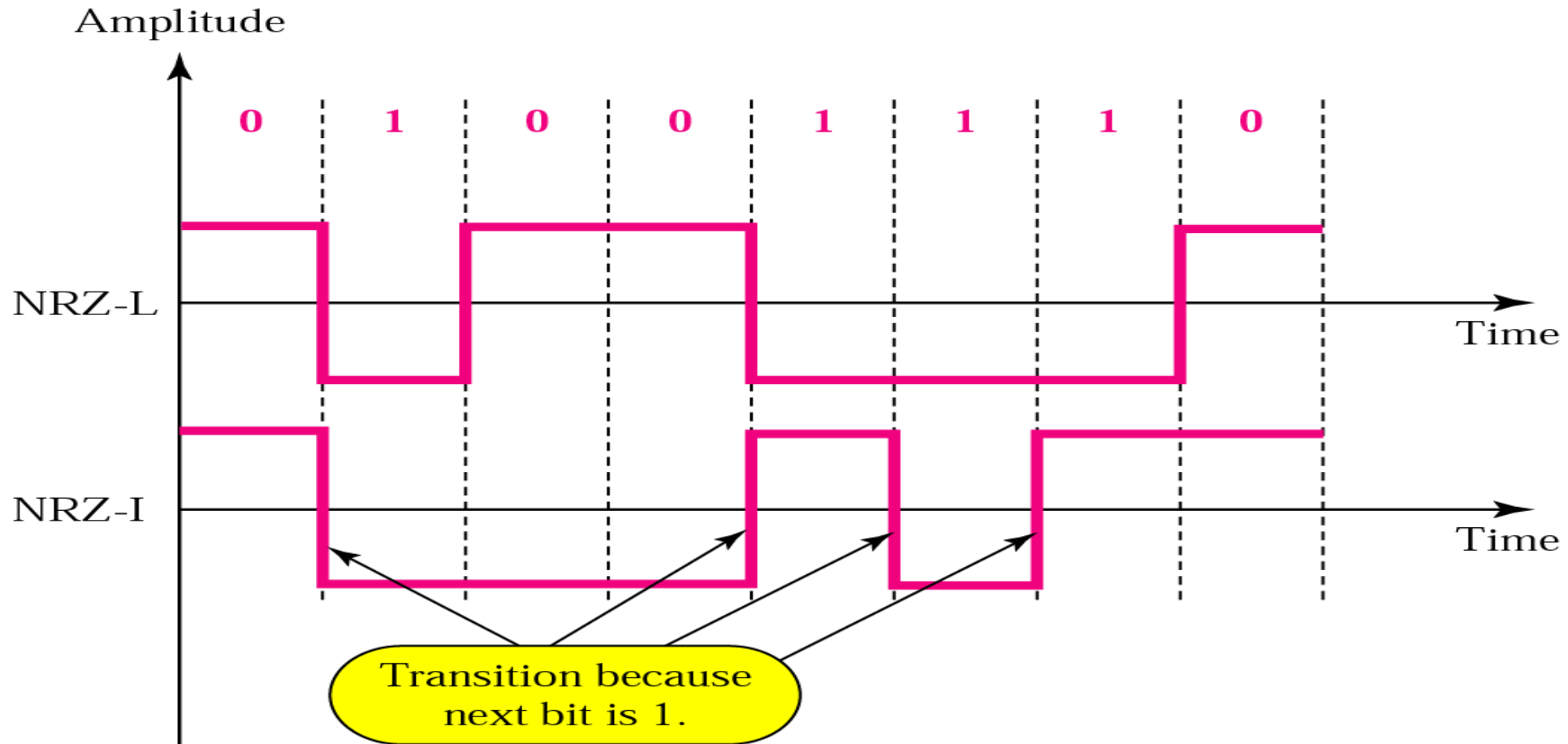
Encoding schemes



Unipolar-NRZ



Polar-NRZ

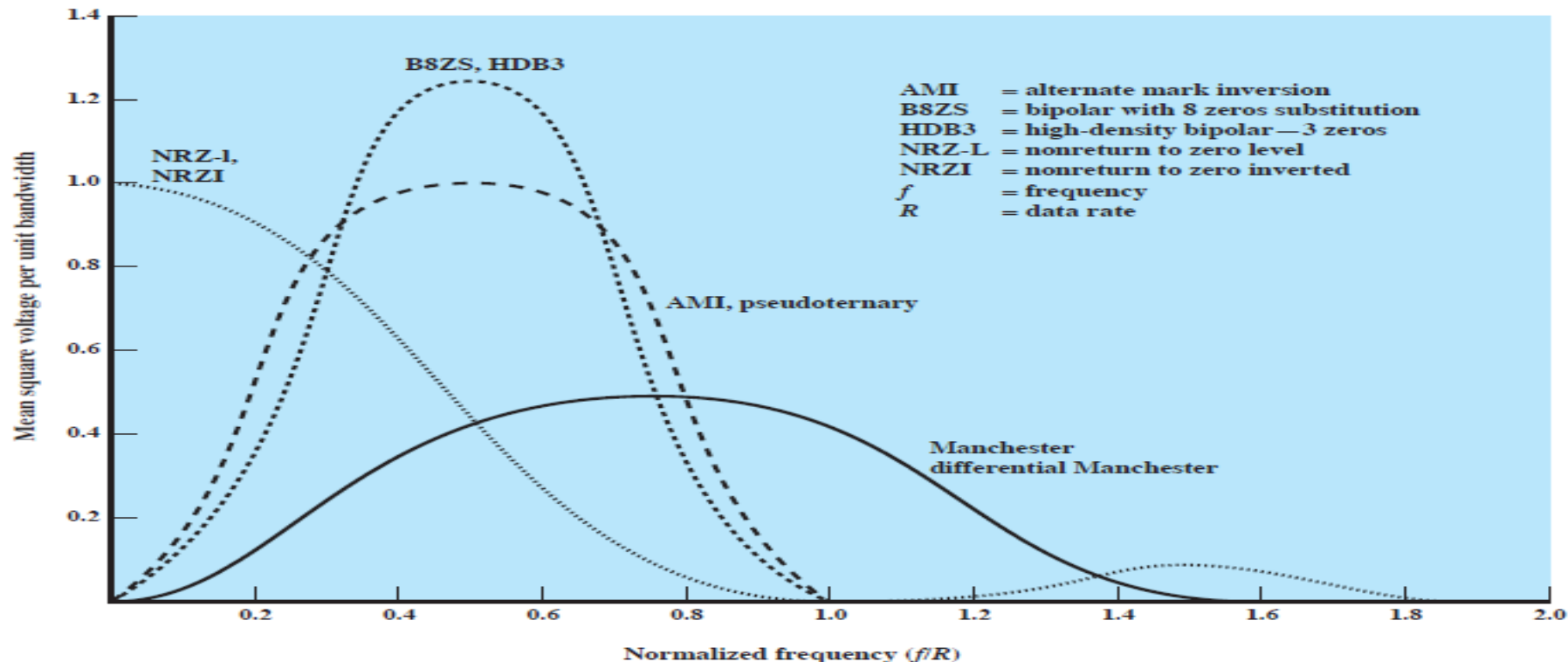


differential encoding: data represented by changes rather than levels

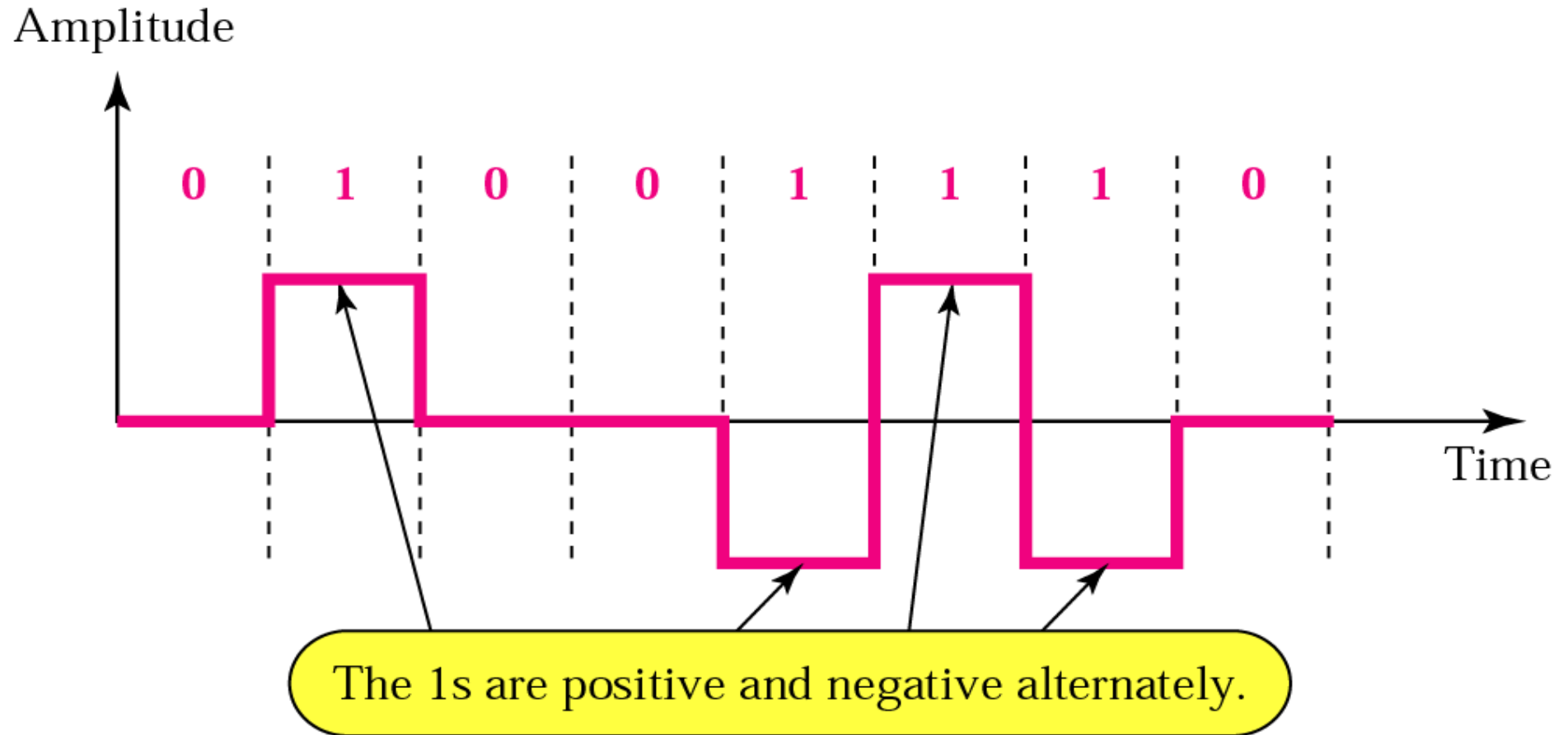
- more reliable detection of transition rather than level
- easy to lose sense of polarity due to wrong wiring

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)

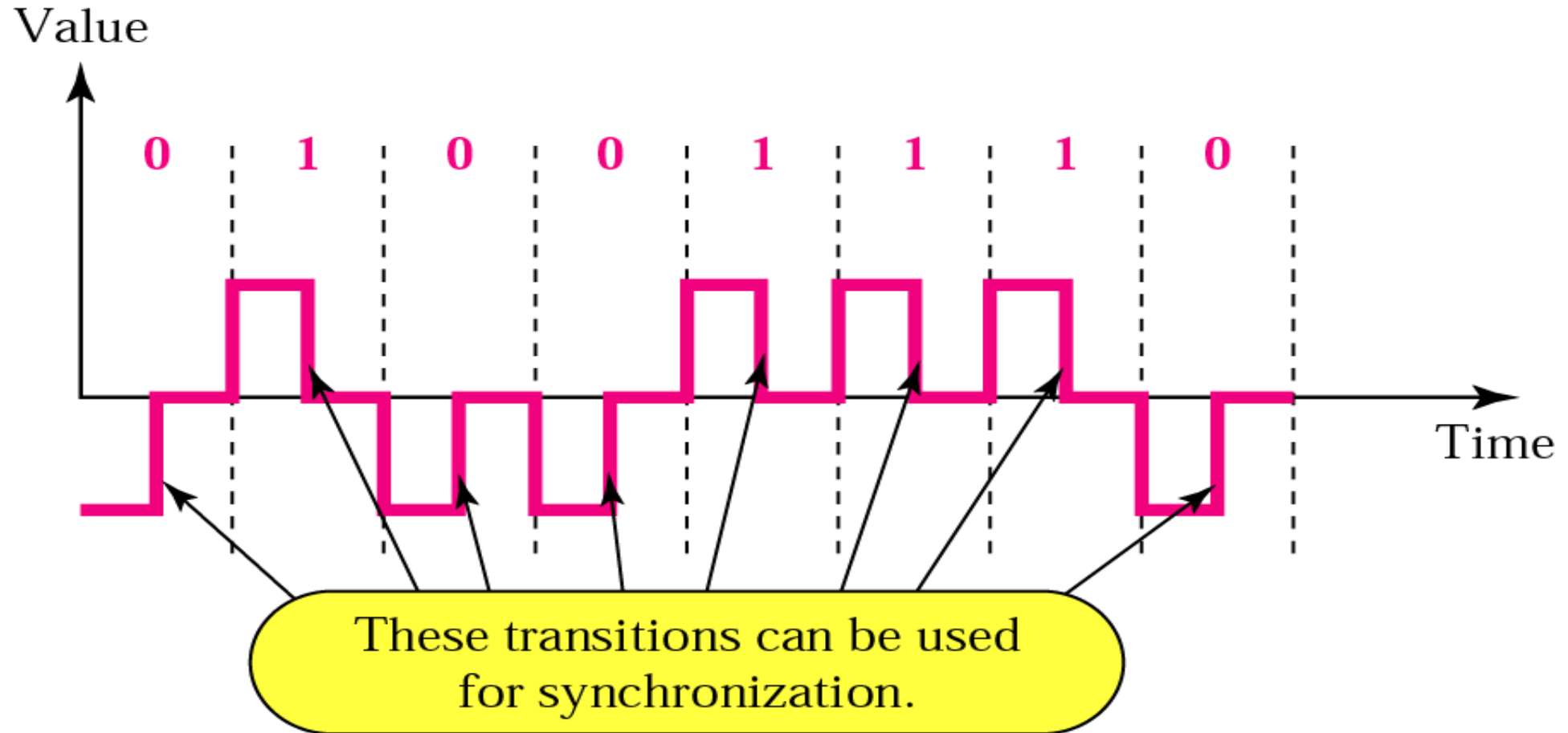


- No DC Component
- Lower bandwidth than NRZ codes
- Easy error detection
- Long runs of 0s still a problem

Biphase coding schemes

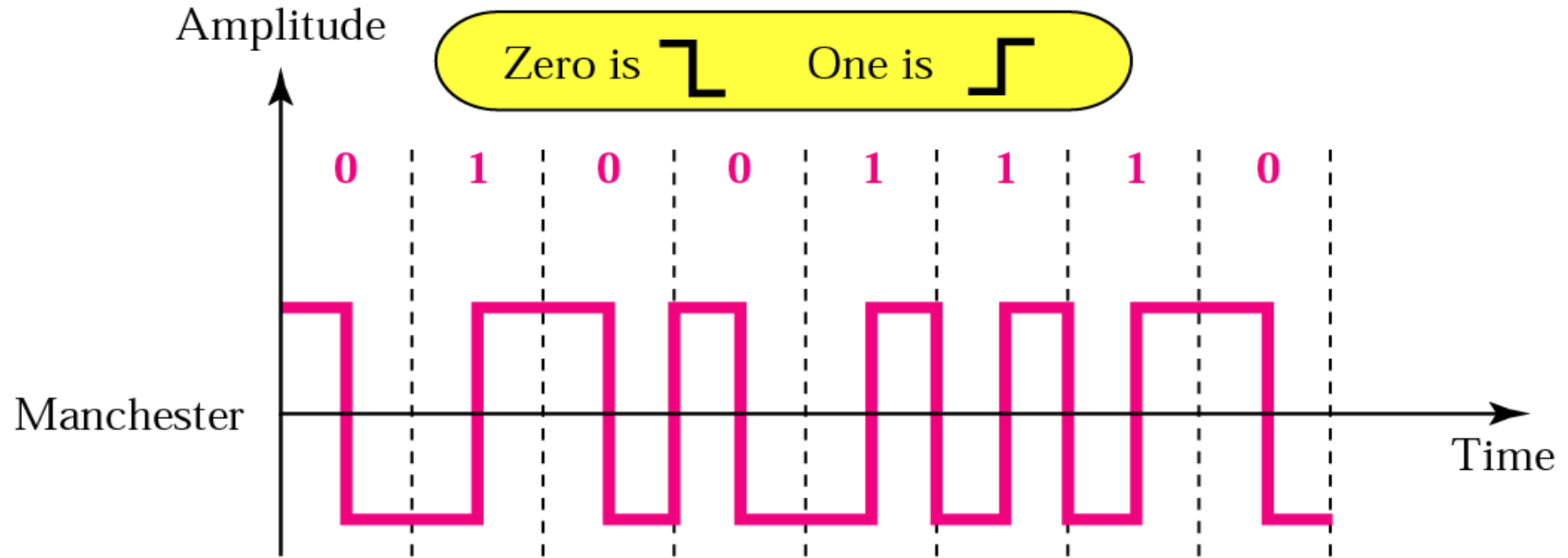
- Transition at the middle of each bit period
- Predictable transition helps receiver synchronization
- No DC component
- Absence of expected transition helps identification of bit flip
- Used popularly in Ethernet

Bipolar-RZ



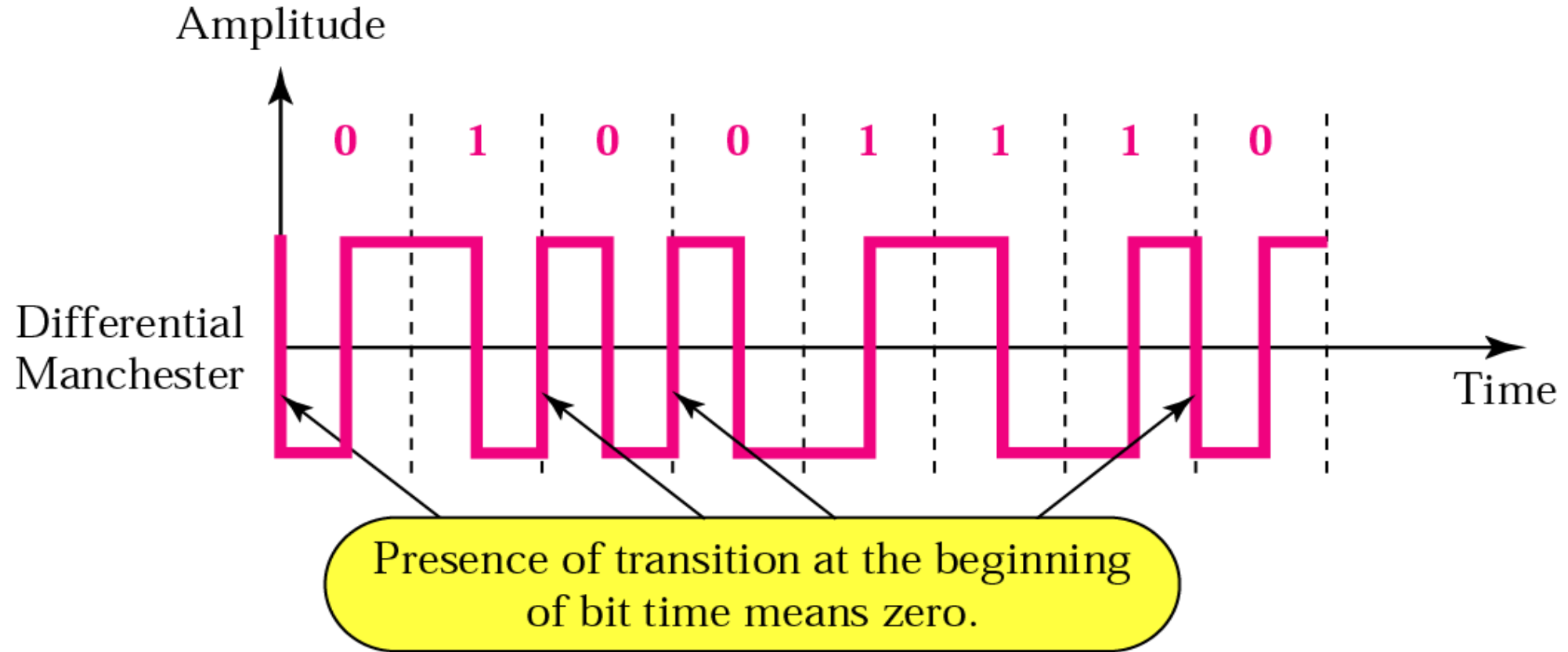
- No DC Component
- No problem with long runs of 1s or 0s
- Wastage of bandwidth for a multilevel scheme
- Requires higher signal power for same BER

Manchester



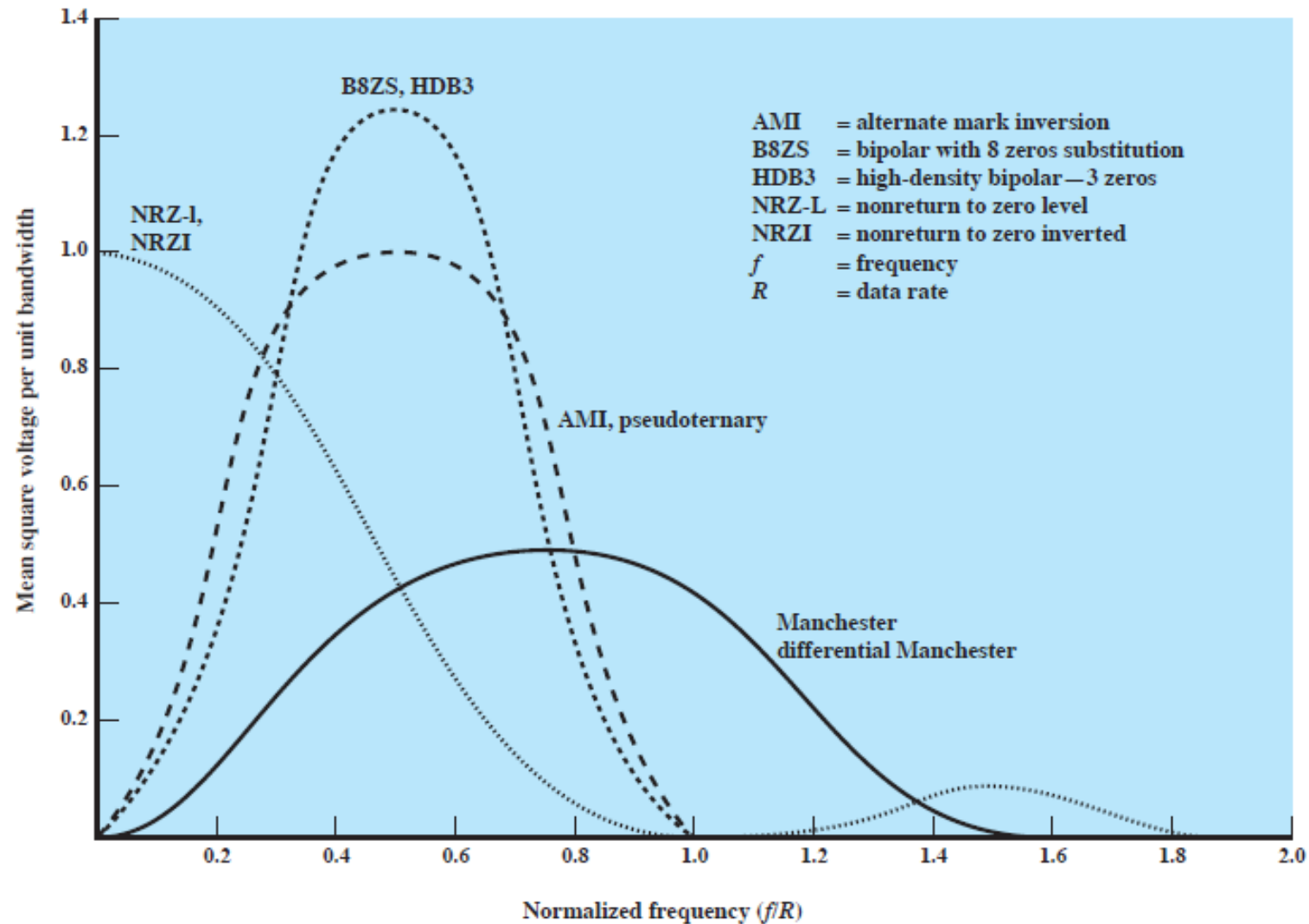
- Transition for clocking and bit representation
- No DC component
- Noise has to invert signal before and after midpoint
- Requires higher bandwidth than other bipolar schemes

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

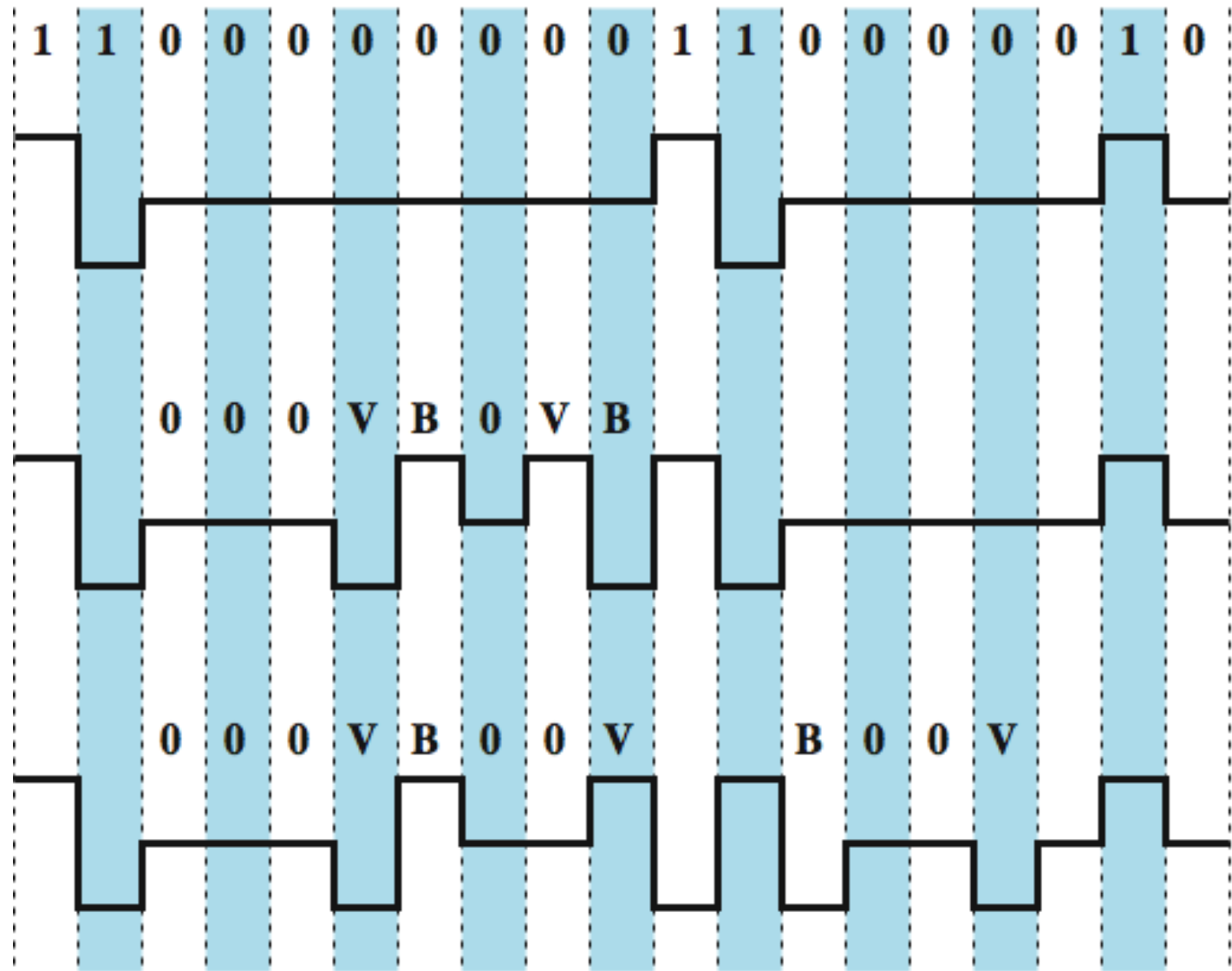
Block coding

- 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

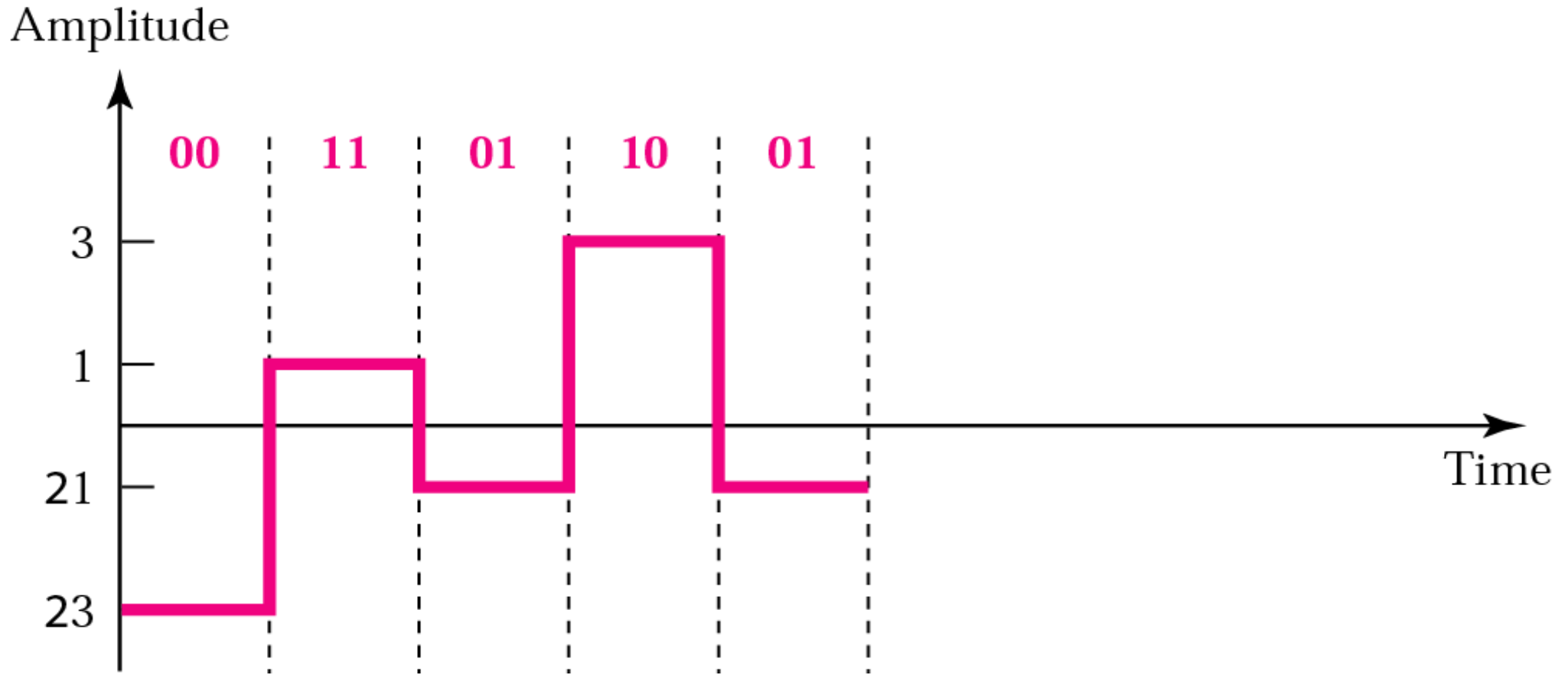


Valid bipolar signal
Bipolar violation

Multi-level schemes

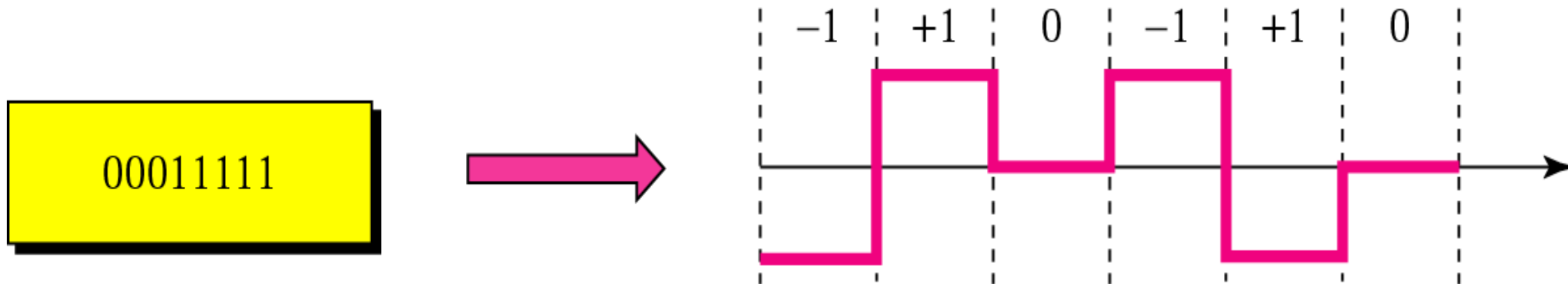
- Increase number of bits per baud
- 2^m data elements on L^n signal patterns; often expressed as mBnL
- Mostly $2^m \leq L^n$;
- Redundancy used for synchronization, error detection, DC balance
- Average baud rate is $n/m * B/2$.
- Combined with parallel transmission to get high data rates
- Complex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

2B1Q



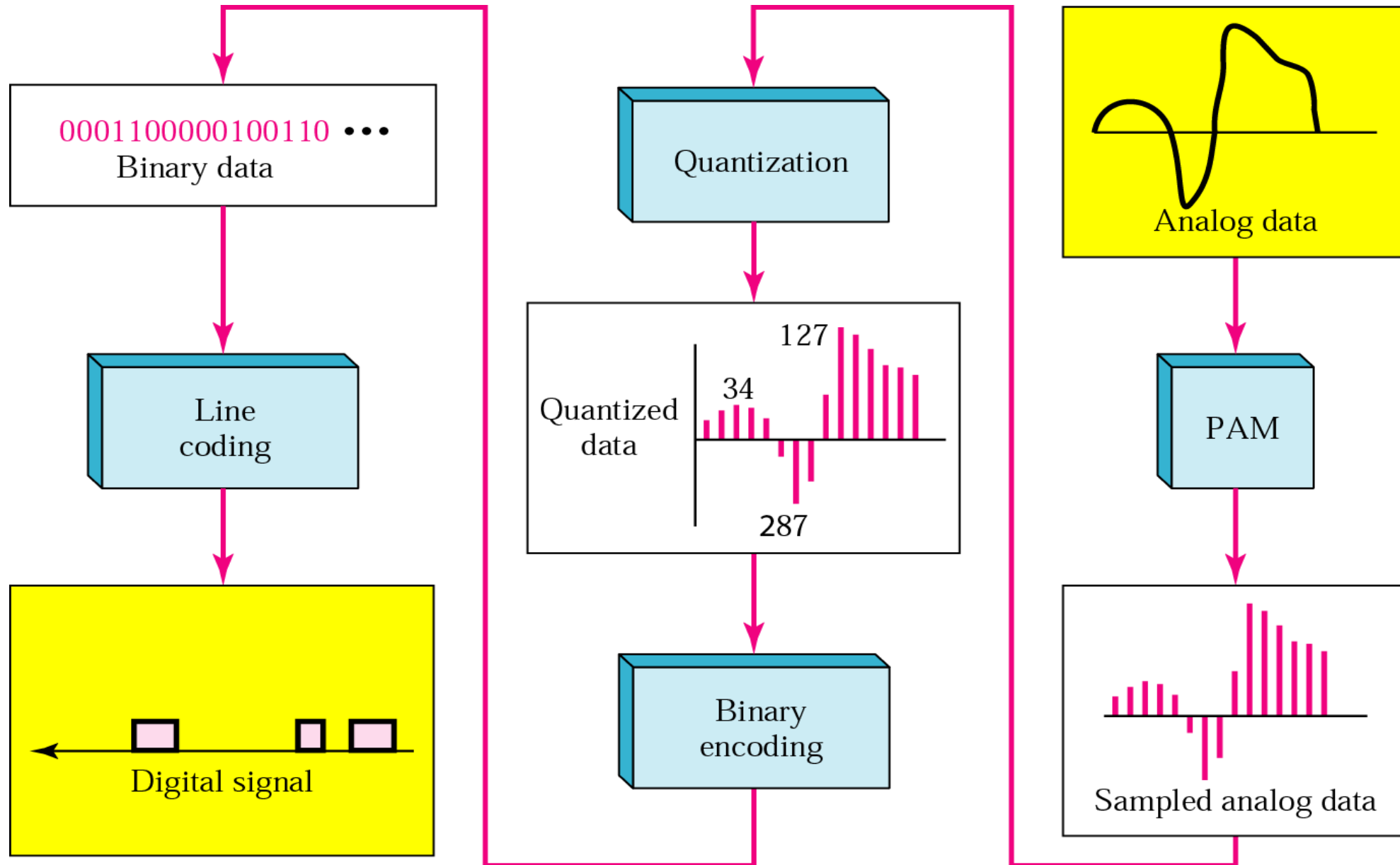
- No redundancy available
- Used in DSL
- Transition table defines the coding scheme
- Requires half bandwidth compared to NRZ-L

8B6T



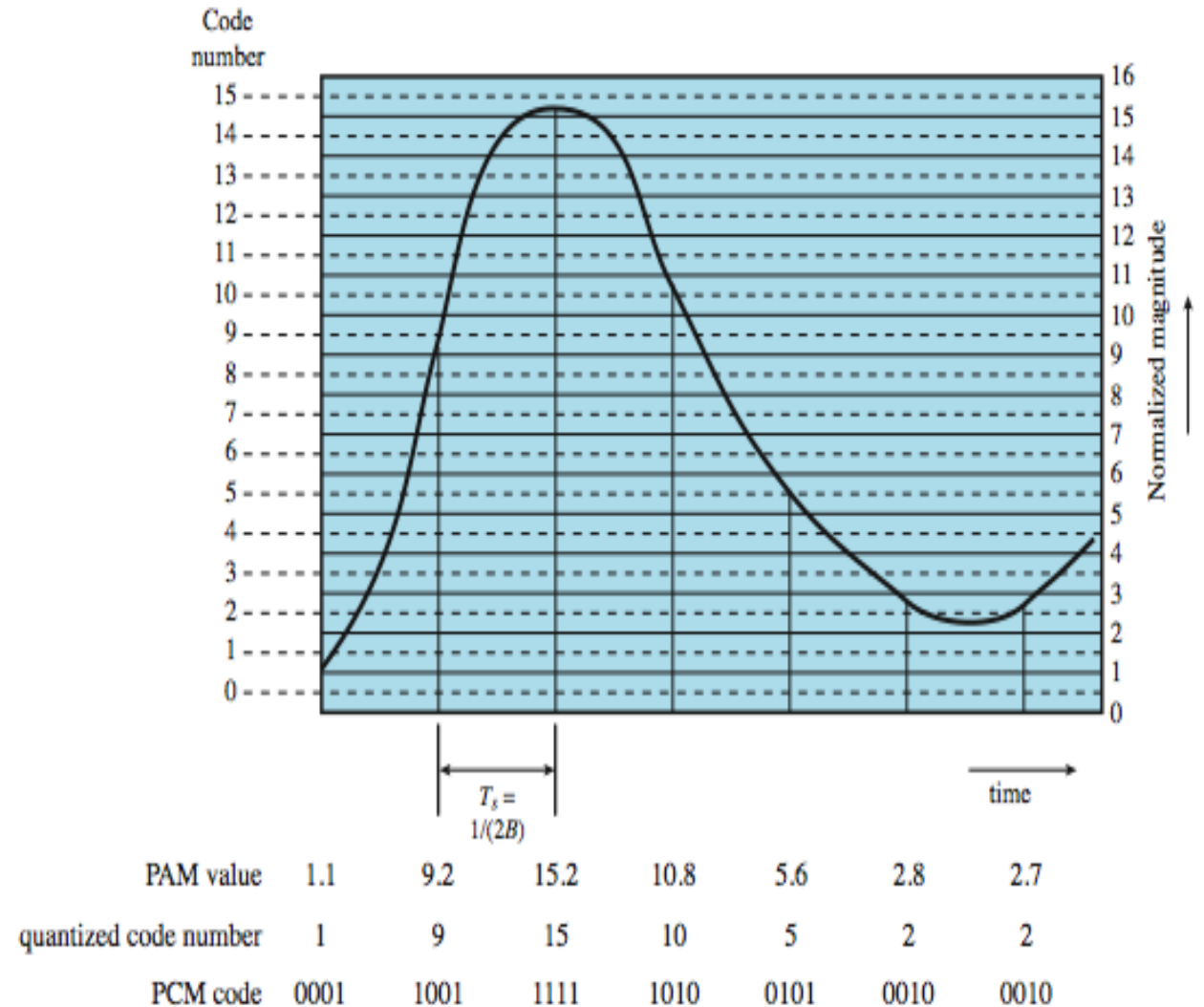
- 256 bit patterns encoded with 478 signal elements
- Redundancy used for DC balance, synchronization, error detection
- Sender keeps track of weight; signal always has 0 or +1 weight
- Pattern inverted before transmission to produce -1 weight
- Synchronization patterns are introduced during transmission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

Overview of Analog to Digital Conversion



Pulse Code Modulation (PCM)

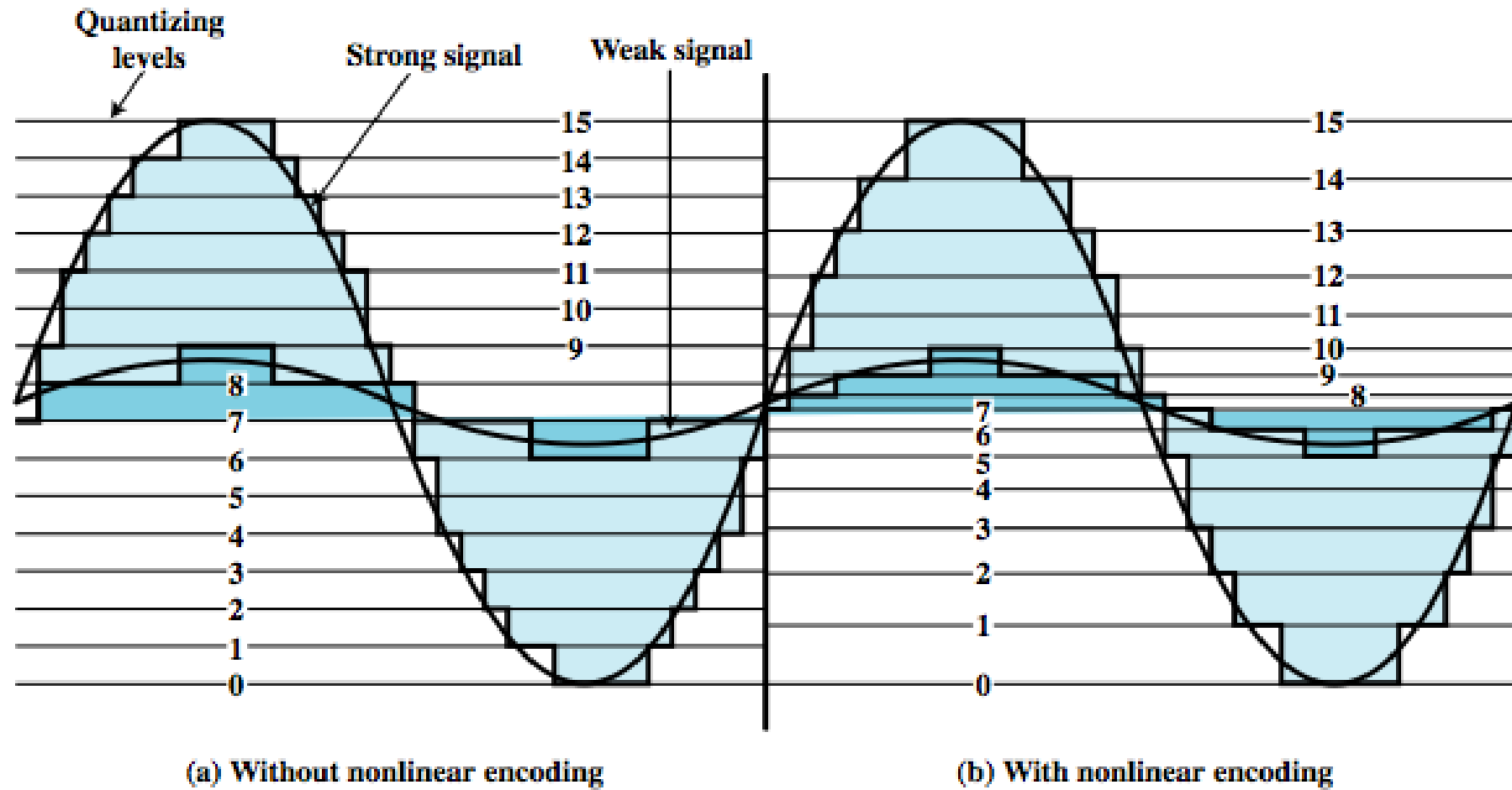
- Nyquist Sampling Rate
 - Uniform sampling rate twice the highest frequency is enough
- Pulse amplitude modulation signal
- Discretized by quantization
- Coded in m-digits
- Quantization error or noise
 - Depends on V and m
- $\text{SNR} = 6.02m + 1.76 \text{ dB}$



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



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

