Digital and Analog Transmission

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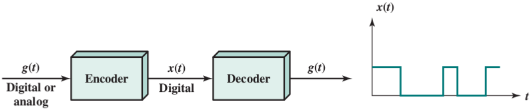
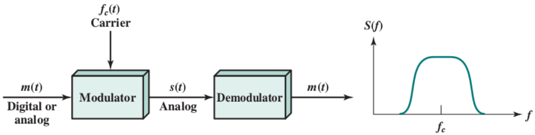
Digital transmission



(a) Encoding onto a digital signal

- Data source g(t) may be digital or analog
- **Encoded** into a digital signal x(t)
- Form of x(t) depends on the encoding technique
- Form of x(t) is chosen to optimize the transmission medium - conserve bandwidth or minimise errors

Analog transmission



- The basis for analog signaling is a continuous constant-frequency signal known as the **carrier signal**
- The frequency of the carrier signal is chosen to be compatible with the transmission medium being used.
- Data may be transmitted using a carrier signal by modulation.
- **Modulation** is the process of encoding source data onto a carrier signal with frequency f_c.
- All modulation techniques involve operation on one or more of the three fundamental carrier signal parameters: amplitude, frequency, and phase.

Analog transmission

- Input signal m(t) may be digital or analog
- m(t) is called the **baseband** signal or the **modulating** signal
- The result of modulating the carrier is the modulated signal s(t)
- s(t) is a bandlimited or bandpass signal
- The location of the bandwidth on the spectrum is related to f_c and is often centered on f_c .
- Form of s(t) is chosen to optimize the transmission medium - conserve bandwidth or minimise errors

Comparing all combinations

- Digital data, digital signal: Encoding equipment is less complex and less expensive compared to digital-to-analog modulation equipment
- Analog data, digital signal: Digital transmission is preferred, as discussed earlier
- Digital data, analog signal: Some transmission media, such as optical fiber and unguided media, will only propagate analog signals
- Analog data, analog signal: Analog data in electrical form can be transmitted as baseband signals easily and cheaply. Example?

All four are widely used today

A common use of modulation

- Shift the bandwidth of a baseband signal to another portion of the spectrum.
- In this way multiple signals, each at a different position on the spectrum, can share the same transmission medium.
- Called **Frequency Division Multiplexing (FDM)**

A common use of modulation

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Digital data, digital signals

- Binary data are transmitted by encoding each data bit into **signal elements** (the shortest unit (timewise) of a signal)
- The simplest case: one-to-one correspondence between bits and signal elements — 1 : lower voltage level, 0 : higher voltage level
- Data elements are what we want to send, signal elements are what we can send
- r = number of data elements / number of signal elements.
- Analogy: Each data element is a person, each signal element is a vehicle

Question

Consider the following cases: a) Each person is driving a vehicle. b) More than one person is travelling in a vehicle c) One person is driving a car and a trailer.
What are the values of r in each case?

(A) $1, > 1, < 1$

(B) $1, 1, 1$

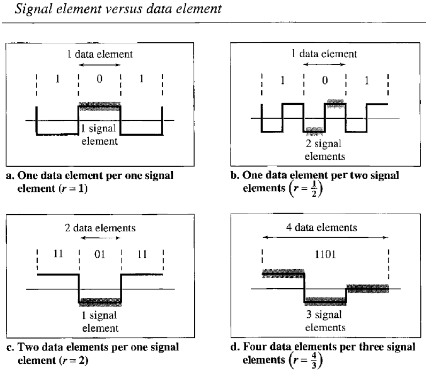
(C) $1, < 1, > 1$

(D) Can't say

Digital data, digital signals

- **Unipolar signals**: all signal elements have the same algebraic sign
- **polar signals**: one logic state is represented by a positive voltage level and the other by a negative voltage level
- **bipolar signals:** there are 3 signal levels: positive, zero and negative
- **data signaling rate, or data rate** of a signal: the rate, in bits per second, at which data are transmitted
- duration or length of a bit is the amount of time it takes for the transmitter to emit the bit
- **modulation rate**: the rate at which the signal level is changed. Expressed in **bauds**: signal elements per second
- The modulation rate depends on the nature of the **digital encoding**
- Digital encoding: Mapping from data bits to signal elements

Signal elements and data elements



- Our goal is to increase data rate and decrease the modulation rate.
- When we decrease the modulation rate, bandwidth requirement is decreased
- When more people are carried in one car, traffic jams reduce — less bandwidth of the transportation system is used

Digital transmission terms

Term	Units	Definition
Data element	Bits	A single binary one or zero
Data rate	Bits per second (bps)	The rate at which data elements are transmitted
Signal element	Digital: a voltage pulse of constant amplitude Analog: a pulse of constant frequency, phase, and amplitude	That part of a signal that occupies the shortest interval of a signaling code
Signaling rate or modulation rate	Signal elements per second (baud)	The rate at which signal elements are transmitted

Question

1) Interpreting digital signals at a receiver requires that the receiver must know with some accuracy when a bit begins and ends
2)Interpreting digital signals at a receiver requires that the receiver must determine whether the signal level for each bit position is high (0) or low (1)
3) The signal level is determined by sampling each bit position in the middle of the interval and comparing the value to a threshold.
Which of these statements is true?

(A) 1,2 and 3
(B) Only 1 and 2
(C) Only 3
(D) none of the above

Success in interpreting an incoming signal

With other factors held constant, the following statements are true:

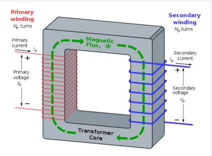
- An increase in data rate increases bit error rate (BER)
- An increase in SNR decreases bit error rate.
- An increase in bandwidth allows an increase in data rate

One more factor

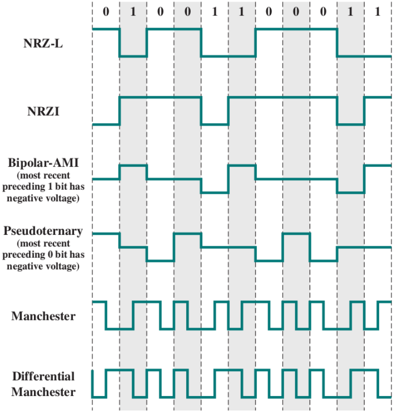
An encoding scheme can also be used to improve the success of a receiver interpreting a received signal. How?

Comparing encoding schemes

- Spectral efficiency
  - Desirable — less high frequency components : less bandwidth and less distortion (why?)
  - Desirable — no DC component : no physical attachment of connections required, can use AC transformers, thus providing electrical isolation and suppressing electrical noise
- Clocking: The transmitted clock can be embedded into the digital signal using an encoding scheme
- Error detection scheme
- Signal interference and noise immunity (expressed in BER)
- Cost and complexity: The higher the modulation rate w.r.t a data rate, the higher the cost



Digital encoding schemes



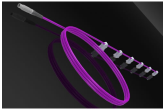
Nonreturn to Zero-Level (NRZ-L)
0 = high level
1 = low level
Nonreturn to Zero Inverted (NRZI)
0 = no transition at beginning of interval (one bit time)
1 = transition at beginning of interval
Bipolar-AMI
0 = no line signal
1 = positive or negative level, alternating for successive ones
Pseudoternary
0 = positive or negative level, alternating for successive zeros
1 = no line signal
Manchester
0 = transition from high to low in middle of interval
1 = transition from low to high in middle of interval
Differential Manchester
Always a transition in middle of interval
0 = transition at beginning of interval
1 = no transition at beginning of interval

NRZI: If the next bit is 1, there is an inversion. If the next bit is 0, there is no inversion

Differential encoding

NRZI is an example

- information to be transmitted is represented in terms of the changes between successive signal elements rather than the signal elements themselves
- If the current bit is a binary 0, then the current bit is encoded with the same signal as the preceding bit
- If the current bit is a binary 1, then the current bit is encoded with a different signal than the preceding bit.
- It may be more reliable to detect a transition in the presence of noise than to compare a value to a threshold
- On a multidrop twisted-pair line, if the leads from an attached device to the twisted pair are accidentally inverted, all 1s and 0s for NRZ-L will be inverted — this will not happen for differential encoding



Root Mean Square Voltage

- The RMS value is the square root of the mean (average) value of the squared function of the instantaneous values
- $V_{RMS} = \sqrt{\frac{1}{T}\int_0^T {V_m}^2 \cos^2(\omega t)dt}$
- Integrating through with limits taken from 0 to 360^0,
  $V_{RMS} = \sqrt{\frac{V_m^2}{2T}\left[t + \frac{1}{2\omega}\sin(2\omega t)\right]_0^T}$
- Since $\omega = \frac{2\pi}{T}$, $V_{RMS} = \frac{V_m}{\sqrt{2}}$

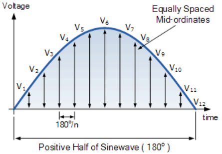
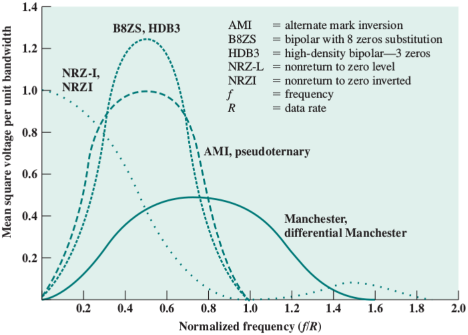


Figure:https://www.electronics-tutorials.ws/accircuits/rms-voltage.html

NRZ codes



- NRZ codes make efficient use of bandwdith.
- Limitations of NRZ-L and NRZ-I:
  - Presence of a dc component
  - Loss of synchronization between sender and receiver — a series of 0s or 1s lead to a constant voltage over a long period
  - Unattractive for signal transmission (NRZI:USB standard, NRZ-L:magnetic recording)

Bipolar AMI and pseudoternary

- AMI: Alternate Mark Inversion
- Binary 0 : no line signal
- Binary 1: a positive or negative pulse, alternating in polarity
- Advantage: No loss of synchronization if a long string of 1s occur (A long of string of 0s?)
- Advantage: As signals alternate between negative and positive polarities, there is no ______
- Advantage: the bandwidth of the resulting signal is less than the bandwidth for NRZ (see previous figure)
- Advantage: the pulse alternation property provides a simple means of error detection (how?)
- All the above are applicable to pseudoternary

Bipolar AMI and pseudoternary: disadvantage and solution

- A long string of 0s in the case of AMI or 1s in the case of pseudoternary cause problems
- Insert additional bits that force transitions - but is an issue for high speed transmissions
- At high data rates, the data is **scrambled**

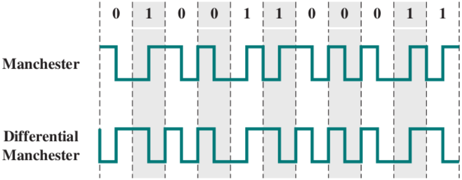
Question

If there are 4 levels in an encoding scheme, each signal level can represent 2 bits of information. With a 3 level encoding scheme (such as pseudoternary), how many bits of information can be represented?

Tradeoffs

- Multilevel binary schemes overcome the problems of NRZ codes
- Not as efficient as NRZ coding. Why?
- $=$ The receiver of multilevel binary signals has to distinguish between three levels ($+$A, A, 0) instead of just two levels in the signaling formats previously discussed
- $=$ requires approximately 3 dB more signal power than a two-valued signal for the same probability of bit error
- $=$ the bit error rate for NRZ codes, at a given SNR is significantly less than that for multilevel binary codes
- **Biphase** coding overcomes the limitations of NRZ codes

Biphase encoding schemes



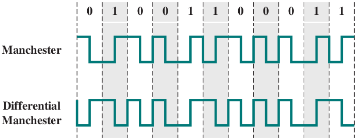
- Manchester: mid-bit transition
  - as a clocking mechanism and also data
  - low-to-high: 1, high-to-low: 0
- Differential Manchester: mid-bit transition: only for clocking
  - the presence of a transition at the beginning of a bit period: 0
  - the absence of a transition at the beginning of a bit period: 1
  - Advantage: differential encoding

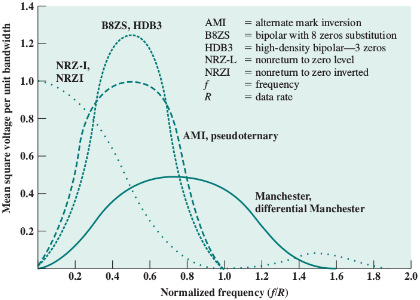
Biphase encoding schemes

- The modulation rate (or the baud rate) determines the bandwidth of a signal, not the data rate
- The number of vehicles affect the traffic, not the number of people carried by them
- Biphase encoding schemes require at least 1 transition per bit time
- The maximum modulation rate is twice that of NRZ
- The bandwidth is correspondingly greater

Biphase encoding schemes - advantages

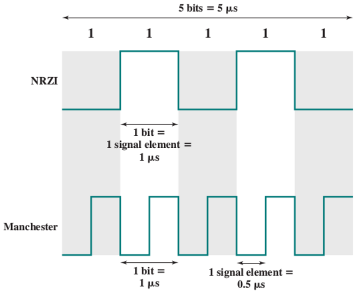
- + there is a predictable transition during each bit time — the receiver can synchronize on that transition — self-clocking codes
- + No DC component
- + The absence of an expected transition can be used to detect noise
- What can cause an undetected error?
- + Reasonable bandwidth (but higher than multilevel binary codes)
- Used in popular techniques for data transmission





Modulation rate

- Must distinguish between data rate (bps) and modulation rate (baud)
- Data rate = $1/T_b$, where T_b is the bit duration
- Modulation rate = rate at which *signal elements* are generated
- Manchester coding: Minimum signal element duration = (1/2) * duration of a bit interval = $(1/2) * T_b$
- For a string of all 0s or all 1s, a continous stream of such pulses is generated
- Max. modulation rate for Manchester encoding = $1 / (T_b/2) = 2/T_b$



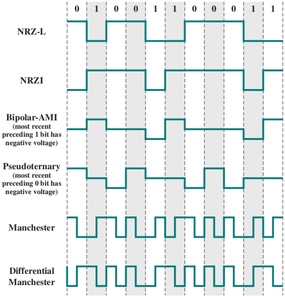
Modulation rate

- Max. modulation rate for Manchester encoding = 1 / (T_b/2)= 2/T_b
- In general, $D = \frac{R}{L} = \frac{R}{\log_2 M}$
- D: Modulation rate in baud, R = data rate, bps M = number of different signal elements = 2^L, L = number of bits per signal element
- For Manchester encoding, let R = 1Mbps. L=1/2. Therefore D= $2 * 10^6$baud.

Modulation rate

- To characterize modulation rates, determine the number of transitions that occur per bit time
- The data streams that produce the highest and the lowest modulation rates are also shown

	Minimum	101010…	Maximum
NRZ-L	0 (all 0s or 1s)	1.0	1.0
NRZI	0 (all 0s)	0.5	1.0 (all 1s)
Bipolar-AMI	0 (all 0s)	1.0	1.0
Pseudoternary	0 (all 1s)	1.0	1.0
Manchester	1.0 (1010…)	1.0	2.0 (all 0s or 1s)
Differential Manchester	1.0 (all 1s)	1.5	2.0 (all 0s)



Schemes with higher modulation rates require higher bandwidth

Scrambling techniques

Example: Bipolar with 8-Zeros Substitution (B8ZS)

- If an octet of all zeros occurs and the last voltage pulse preceding this octet
  - was positive: the eight zeros of the octet are encoded as 000+-0-+
  - was negative, then the eight zeros of the octet are encoded as 000-+0+-
- Sequences that would result in a constant voltage level on the line are replaced
- Filling sequences that will provide sufficient transitions for the receivers clock to maintain synchronization are used
- Filling sequence is replaced by the receiver with the original sequence - thus the data rate is maintained

Question

biphase techniques have achieved widespread use in local area net- work applications at relatively high data rates (up to 10 Mbps).
But they have not been widely used in long distance applications. The principal reason for this is that:

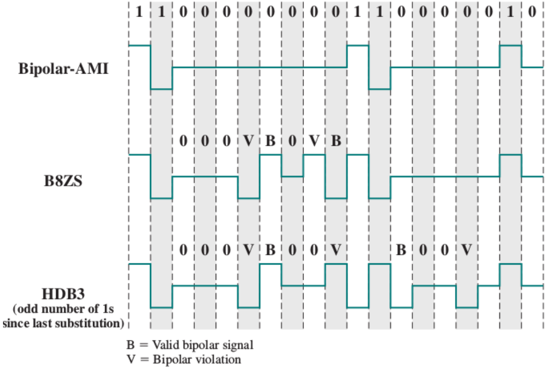
(A) it is difficult to recover clock from the recieved signal

(B) they require a high signalling rate compared to data rate

(C) neither of the above

B8ZS

Bipolar with 8-Zeros Substitution (B8ZS) based on Bipolar AMI



- Last pulse is negative: 000-+0+- , if positive: 000+-0-+
- High-density bipolar-3 zeros (HDB3) is another scheme that uses scrambling.

Requirements of scrambling

- No dc component
- No long sequences of zero-level line signals
- No reduction in data rate
- Error-detection capability

Requirements of scrambling

- Most of the energy is concentrated in a relatively sharp spectrum around a frequency equal to one-half the data rate
- Well suited to high data rate transmission