Data Transmission

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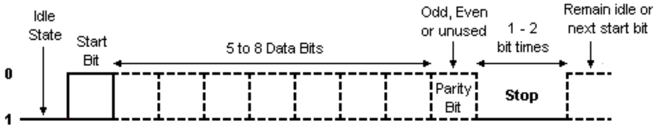
Asynchronous and Synchronous Transmission

- To correctly interpret signals received from the sender, the receiver's bit intervals must correspond exactly to the sender's bit intervals.
- Receiver's clock is faster or slower, bit intervals are not matched
- Suppose the sender transmits 1 bit every μs according to its clock.
- The receiver samples every bit at its center, according to its own clock.
- Suppose the receiver clock is 0.01% faster. The first sampling will be 0.01 of a bit time away from the center of the bit
- After 50 samples, the center will be 50*0.01=0.5 μs away and it may be in error!
- Eventually, the receiver becomes completely out of step with the transmitter
- Synchronization is essential for correct reception

Two approaches for synchronization

- Asynchronous transmission
  - Avoid the timing problem by not sending long, uninterrupted streams of bits.
  - data are transmitted one character at a time, where each character is 5 to 8 bits in length (with start and stop bits)
  - Timing or synchronization must only be maintained within each character; the receiver has the opportunity to resynchronize at the beginning of each new character



Character format in asynchronous transmission

Figure: http://www.technologyuk.net/telecommunications/telecom-principles/synch-and-asynch.shtml

Two approaches for synchronization

- Synchronous transmission: a block of bits is transmitted in a steady stream without start and stop codes. To prevent loss of synchronization:
  - provide a separate clock line between transmitter and receiver; send a pulse from one side to the other
    works well over short distances, but over longer distances the clock pulses are subject to the same impairments as the data signal, and timing errors can occur
  - embed the clocking information in the data signal
    In both the cases, to allow the receiver to determine the beginning of a block of data, a preamble is sent and to determine the end of a block of data, a postamble is sent.

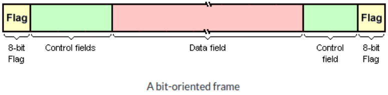


Figure: http://www.technologyuk.net/telecommunications/telecom-principles/synch-and-asynch.shtml

Tranmission Impairments

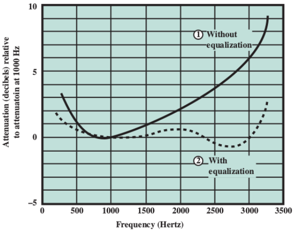
- Attenuation and attenuation distortion
- Delay distortion
- Noise

Attenuation

- Guided media: attenuation is exponential - expressed as number of decibels per unit distance
- Wireless: a more complex function of distance and the makeup of the atmosphere
- Considerations:
  1. A received signal must have sufficient strength so that the electronic circuitry in the receiver can detect and interpret the signal.
  2. The signal must maintain a level sufficiently higher than noise to be received without error.
  3. Attenuation is greater at higher frequencies, and this causes distortion.

Attenuation

- Points 1 and 2: Use of amplifiers and repeaters
- Attenuation distortion: attenuation is different for different frequencies
- Solution: Equalize attenuation over a band of frequencies - amplify high frequencies



(a) Attenuation

$N_f = -10 \log_{10} \frac{P_f}{P_{1000}}$

Attenuation distortion can present less of a problem with digital signals. Why?

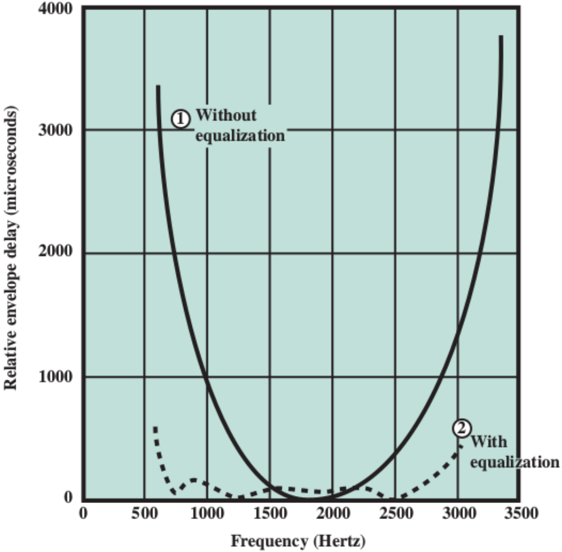
Attenuation

The loss in a cable is usually defined in decibles per kilometer (dB/km). If the signal at the beginning of a cable with $0.3dB/km$ loss has a power of 2mW, what is the power of the signal at 5 km?

Delay distortion

- Occurs only in transmission cables, not in air
- Velocity of propagation of a signal through a cable is different for different frequencies
- For a signal with a given bandwidth, the velocity tends to be highest near the center frequency of the signal and to fall off toward the two edges of the band.
- Effect: various components of a signal will arrive at the receiver at different times
- Critical for digital data: some of the signal components of 1 bit position will spill over into other bit positions, causing intersymbol interference
- Limits bit rate

Delay distortion



(b) Delay distortion

Noise

- Transmitted signal distorted by transmission medium + noise
- noise: unwanted signals inserted between transmission and reception

Noise

- Thermal noise
- Intermodulation noise
- Crosstalk
- Impulse noise

Thermal noise

- Due to thermal agitation of electrons
- A function of temperature
- Uniformly distributed across the bandwidths typically used in communications systems : white noise
- Cannot be eliminated and therefore places an upper bound on communications system performance

Thermal noise

The amount of thermal noise to be found in a bandwidth of 1 Hz in any device or conductor is
$N_0 = kT(W/Hz)$
N_0: noise power density in watts per 1 Hz of bandwidth
k : Boltzmann's constant $= 1.38 * 10^{-23}$ J/K
T: temperature, in Kelvins (absolute temperature) where the symbol K is used to represent 1 Kelvin

Thermal noise

- The dBW (decibel-watt) is used extensively in microwave applications.
- The value of 1 W is selected as a reference and defined to be 0 dBW. The absolute decibel level of power in dBW is defined as:
  $Power_{dBW} = 10 \log \frac{Power_w}{1\ W}$
- Question: Express a power of 1000 W in dBW
- Question: Express a power of 1 mW in dBW
- Another common unit is decibel-milliwatt.
  $Power_{dBm} = 10 \log \frac{Power_{mW}}{1mW}$

Thermal noise

What is the thermal noise power density at room temperature ($17^0 C$)? Express in W/Hz and in dBW/HZ. $k = 1.38 * 10^{-23}$ J/K

Thermal noise

- Thermal noise is assumed to be independent of frequency.
- The thermal noise in watts present in a bandwidth of B hertz is: $N = kTB$
- Given a receiver with an effective noise temperature of 294 K and a 10-MHz bandwidth, the thermal noise level at the receivers output is ______

Intermodulation noise

- Due to signals at different frequencies sharing the same transmission medium
- Effect: to produce signals at a frequency that is the sum or difference of the two original frequencies or multiples of those frequencies
- Example: A signal at 4000HZ and one at 8000 Hz sharing the same transmission facility may produce energy at 12000 Hz.
- Caused because the transmitter, the medium or the receiver are not linear — their output is not the input multiplied by a constant.

Crosstalk

- electrical coupling between nearby twisted pairs (example: a change in current through one wire induces a voltage across the ends of the other wire through electromagnetic induction)
- Microwave antennas picking up unwanted signals
- Usually less than or equal to thermal noise

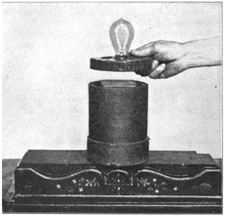


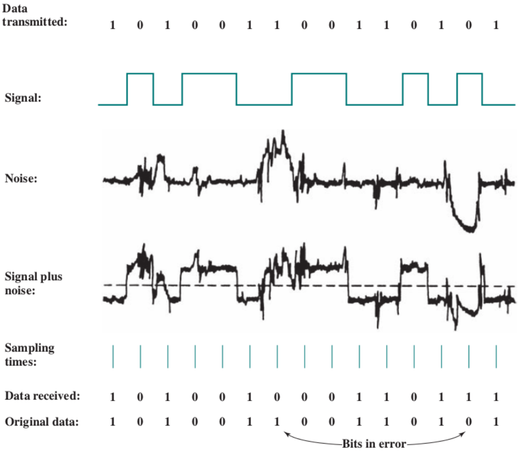
Figure: Example of inductive coupling, Wikipedia

Impulse noise

The type of noises so far have relatively constant and predictable magnitudes

- Impulse noise is noncontinuous
- consists of irregular pulses or noise spikes of short duration and of relatively high amplitude
- A variety of causes: external electromagentic disturbances (example?), faults in the system etc.
- Less impact to analog data
- The primary source of error in digital communication

Effect of noise on a periodic signal



A sharp spike of energy 0.01s on a digital data stream at 56kbps will cause data of 560 bits to be removed.

Channel capacity

Question: to what extent do these impairments limit the data rate that can be achieved?

Channel capacity

The **maximum** rate at which data can be transmitted over a given communication path, or channel, under given conditions, is referred to as the **channel capacity**.

Channel capacity

We are trying to relate the four concepts below:

- Data rate: The rate, in bits per second (bps), at which data can be communicated
- Bandwidth: The bandwidth of the *transmitted signal* as constrained by the transmitter and the nature of the transmission medium, expressed in cycles per second, or hertz
- Noise: The average level of noise over the communications path
- Error rate: The rate at which errors occur, where an error is the reception of a 1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted

Channel capacity

- The greater the bandwidth, the greater the cost
- All transmission channels have limited bandwidth
- Therefore, we need to make efficient use of bandwidth

For digital data: as *high a data rate* as possible at a particular *limit of error rate* for a given *bandwidth*

Nyquist Bandwidth

Consider a noise-free channel

- If the signals to be transmitted are binary (have only 2 voltage levels) the highest data rate C_r that can be supported if the bandwidth is B is 2B bps.
- In general, $C_r = 2B \log_2 M$, where M is the number of discrete voltage levels.
- For example, if 4 voltage levels are used (M=4), each level can represent two bits (00, 01, 10, 11).
- For a given bandwidth, the data rate can be increased by increasing the number of different signal elements
  - The receiver has to distinguish more levels
  - Noise and other impairments will limit the value of M

Example: A voice channel of bandwidth 3100Hz is used to transmit data. What is the maximum data rate that can be supported if there are 2 levels? If there are 8 levels?

Discussion

- Does the Nyquist bit rate agree with the intuitive discussion we had earlier?
- We need to distinguish between the bandwidth of a signal and the bandwidth of the channel carrying that signal
- Case I : We take f and the first two harmonics, 3f and 5f
  Bandwidth of the signal = 5f-f= 4f = 4 MHz, assuming f=1 MHz.
  Period T = 1/f = 1 μs. Assuming we need to transmit 1010.., 1 bit occurs every 0.5μs. Data rate = 1 bit /0.5 μs= 2Mbps.
- Let us use only f and no harmonic frequencies (the worst case, that is, the worst signal). On a *channel* with B=1MHz, we can transmit only f=1MHz and therefore, the maximum data rate that can be achieved = 2 Mbps

Discussion

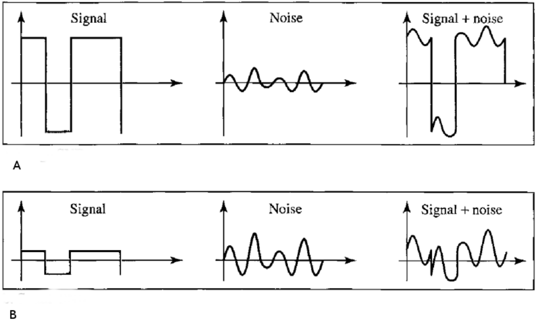
- On a *channel* with B=2MHz, we can transmit f=2MHz and therefore, the maximum data rate that can be achieved = 4 Mbps. We can also transmit a signal with a data rate of 2Mbps on the same channel, with higher harmonics (better quality).
- Conversely, the *minimum* bandwidth of a channel required to carry a 2 Mbps data rate is 1MHz.
- **The discussion on this slide and the previous one assumes that M=2 and that the channel is noise-free**.

Noisy Channels

Consider a channel that has noise.

- If data rate is increased, then more bits will occur during the interval of a noise spike, and hence more errors will occur.
- For a given level of noise, we would expect that a greater signal strength would improve the ability to receive data correctly in the presence of noise.
- signal-to-noise ratio (SNR, or S/N) is:
  $SNR_{dB} = 10 \log_{10} \frac{averagesignalpower}{averagenoisepower}$
- SNR is measured at the receiver
- This expresses the amount, in decibels, that the intended signal exceeds the noise level

Question



The above picture shows

(A) A-High SNR, B-High SNR

(B) A-High SNR, B-Low SNR

(C) Hard to say

(D) A-Low SNR, B-High SNR

Question

The values of SNR and SNR_{dB} for a noiseless channel are

(A) inifinity, infinity

(B) 0, infinity

(C) infinity, 0

(D) 0,0