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Lecture 5

Plan: Finish 2.1

1. Overview of chapter 2: deals with how the bits are transmitted. → more of engineering concepts.

Topics: basic theory, transmission medium, modulation, and signal multiplexing

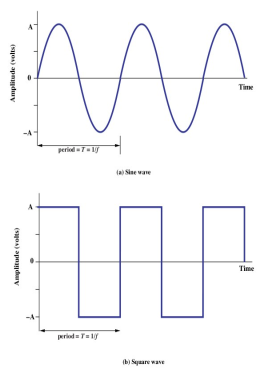
2. Basic concepts:

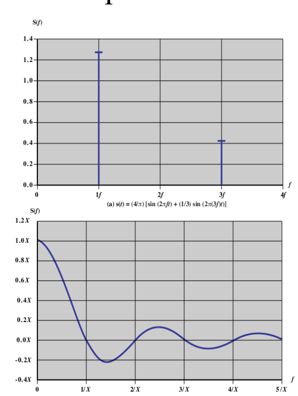
We are interested in transmission media, how data is transmitted over them, and the communications systems that use them.
One thing all transmission media have in common is that data is transmitted on *waves*. So we need to consider some of the physical properties of waves.

Fourier series
Waves are periodic functions. Every periodic function can be expressed as a Fourier series, which is an infinite series whose terms are sine and cosine functions. Each term of a Fourier series is a sine or cosine function of a different frequency; each frequency is an integral multiple of the fundamental frequency.

$$f(x) = \tfrac{1}{2}a_0 + \sum_{n=1}^{\infty} a_n \cos(nx) + \sum_{n=1}^{\infty} b_n \sin(nx)$$

Usually, the cos and sin coefficients are expressed as $a_n + i\, b_n$
The decomposition is unique. That is, given a periodic function f, the coefficients a_n and b_n which comprise the Fourier series can be determined uniquely. Likewise, the function f can be reconstructed if the Fourier coefficients are known.
==> Something fundamental is going on here. A signal on a wire (or some other medium) is really a bundle of signals at different frequencies. ==> especially for a digital signal because digital signals have a much wider spectrum.





One implication has to do with the difference between digital and analog signals.

Suppose we want to send a series of bits, with 0's and 1's represented by two different voltage levels, as we might find on the wires within a CPU.

This waveform has a representation as a Fourier series. That is, it can be decomposed into a sum of sine and cosine waves. However, the a_n and b_n coefficients don't tend to 0 quickly. Many terms are needed to give a good approximation to the actual signal. A *wide spectrum* is required. (Demonstrate using matlab code about how fourie transform works fftFrequency.m)

This causes problems when transmitting over any real medium.

- Voice-grade telephone lines do not transmit signals above 3000 Hz. (The range is about 300 - 3000 Hz) So much of the signal is filtered out. The result is that only an approximation of the original signal is transmitted and received.
- Over long distances, different frequencies have different characteristics with respect to *attenuation* (signal fade due to loss of energy) and delay distortion (different speeds, so that some components may become out-of-phase with others).
- It would waste bandwidth. One signal would need to use a wide range of frequencies.

Modulation Allows digit to transmit over anoloy "wire"

As a result, what is done is to have a continuous signal called a *carrier* at a certain frequency:

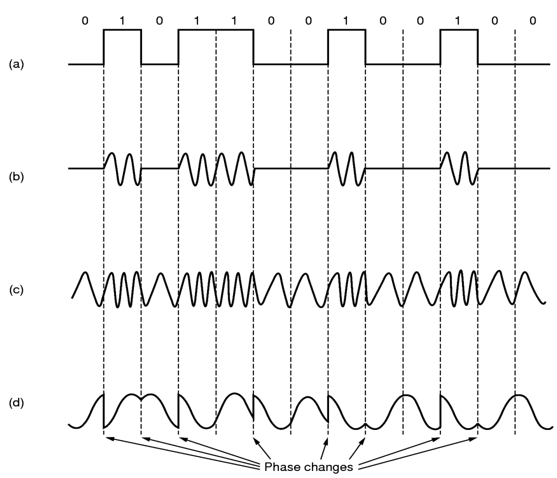
Data is then encoded by making small changes in the signal. This is called *modulation*. (as in AM = amplitude modulation and FM = frequency modulation radio) PM=(PHONE)

analg=>voice-grade wire :30 hz-3khz
digit=>optical wire:10ghz

Three types of modulation:

- Amplitude modulation use a carver signal to transmit => 1= signal | 0 = no
  - susceptible to noise
- Frequency modulation
  - two carriers -- requires more bandwidth
- Phase modulation
  - skip a chunk of the wave
  - permits more than one signal per band

need 2 carriers waves =>
pro: less
can: shorter



AM

Some terminology 15 Mbps bit/second

- baud rate (or signal rate) number of symbols (signal changes) per second. 300 baud = 300 symbols per second a baud is a bit||| 300baud = 300Mbps
- bit rate (or data rate) number of bits per second
- bandwidth: range of frequencies which can be transmitted -- measured in cycles per second → property of the transmission medium

How are they related?

e.g. voltage +5 =1, voltage -5 =0. suppose the bandwidth is 1M Hz, then each period is 10^{-6} s. Each symbol will last half of the period. Thus the bit rate is 2Mbps

If we use four symbols to represent our values and each symbol will last ¼ of a period.

-1v -->00 1v -->01, 2v--> 10 5v → 11.

Then suppose the bandwidth is still 1M Hz, then each period is 10^{-6} s. But each period can transmit 4 symbols/8bits. So the baud rate is 1/(10^-6)/4=4M symbols/sec, bit rate =2*baud=8Mbps.

Q:/What is the relationship between sampling frequency and the frequency of the signal? A:/ Nyquist theorem

Q:/ What about noise in the channel? A:/ Shannon's theorem

Q:/ What is sampling frequency? → The same as the signal frequency (it is how fast our data is sampled).

Changing the signal faster than two times the highest frequency of the original data does no good -- they will appear as higher frequency signals and be filtered out.

Nyquist's theorem
Let H = bandwidth
Let V = number of discrete signal levels

The the maximum data rate = $2H\log_2 V$ bits per second =2H*# of bits per baud

That's with no noise. If channel is noisy, the maximum rate may be less. It is impossible to achieve in real life.

Shannon's theorem
Let S/N = signal to noise ratio of a channel

Max data rate(capacity) = H log2(1 + S/N)
H: Bandwidth of the wire
S/N : signel to noise ratio

The quantity $10 \log_{10} S/N$ is measured in decibels

If sig to noise ratio is 30 dB, then $S/N = 10^3 = 1000$

Then maximum data rate (channel capacity)= $H \log_2 (1 + S/N)$

Q:/ Given a telephone system with SNR = 30dB, bandwidth of 3.1k Hz. How many symbols will be needed to achieve the maximum channel capacity?

A:/

SNR=30dB → SNR in decimal is 1000. Thus, the maximum capacity=$3.1k*\log_2(1+1000)$=30898 bps.

If this is achieved, then the number of signal levels can be found as

$C=2*3.1k*\log_2 M$ → M=32.

Wire : 1Mhz
maxdata rale = 2*1m*128 =
14Mbps