COMPUTER NETWORKS
- Chapter 2. The Physical Layer 1

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The physical layer

- defines the mechanical, electrical, and timing interfaces to the network, provides the means to transmit bits from sender to receiver, that is, involves a lot on how to use (analog) signals for digital information.

Theoretical Basis

- Information can be transmitted on wires by varying some physical property such as voltage or current. By representing the value of this voltage or current as a single-valued function of time, f(t), we can model the behavior of the signal and analyze it mathematically. This analysis is the subject of the following sections.

Fourier Series

- Any reasonably behaved periodic function, $g(t)$, with period T can be constructed by summing a (possibly infinite) number of sines and cosines:

$$I \quad V = -E + \sum_{P=}^{\infty} C_P \mathrm{UKP} \quad \pi PHV + \sum_{P=}^{\infty} D_P \mathrm{EQU} \quad \pi PHV$$

where f=1/T is the fundamental frequency and a_n and b_n are the sine and cosine amplitudes of the nth harmonics (terms).

Fourier Series

$$\int_0^T \sin(2\pi k f t)\,\sin(2\pi n f t)\,dt = \begin{cases} 0 \text{ for } k \neq n \\ T/2 \text{ for } k = n \end{cases}$$

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi n f t)\,dt$$

$$b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi n f t)\,dt \qquad c = \frac{2}{T}\int_0^T g(t)\,dt$$

An example

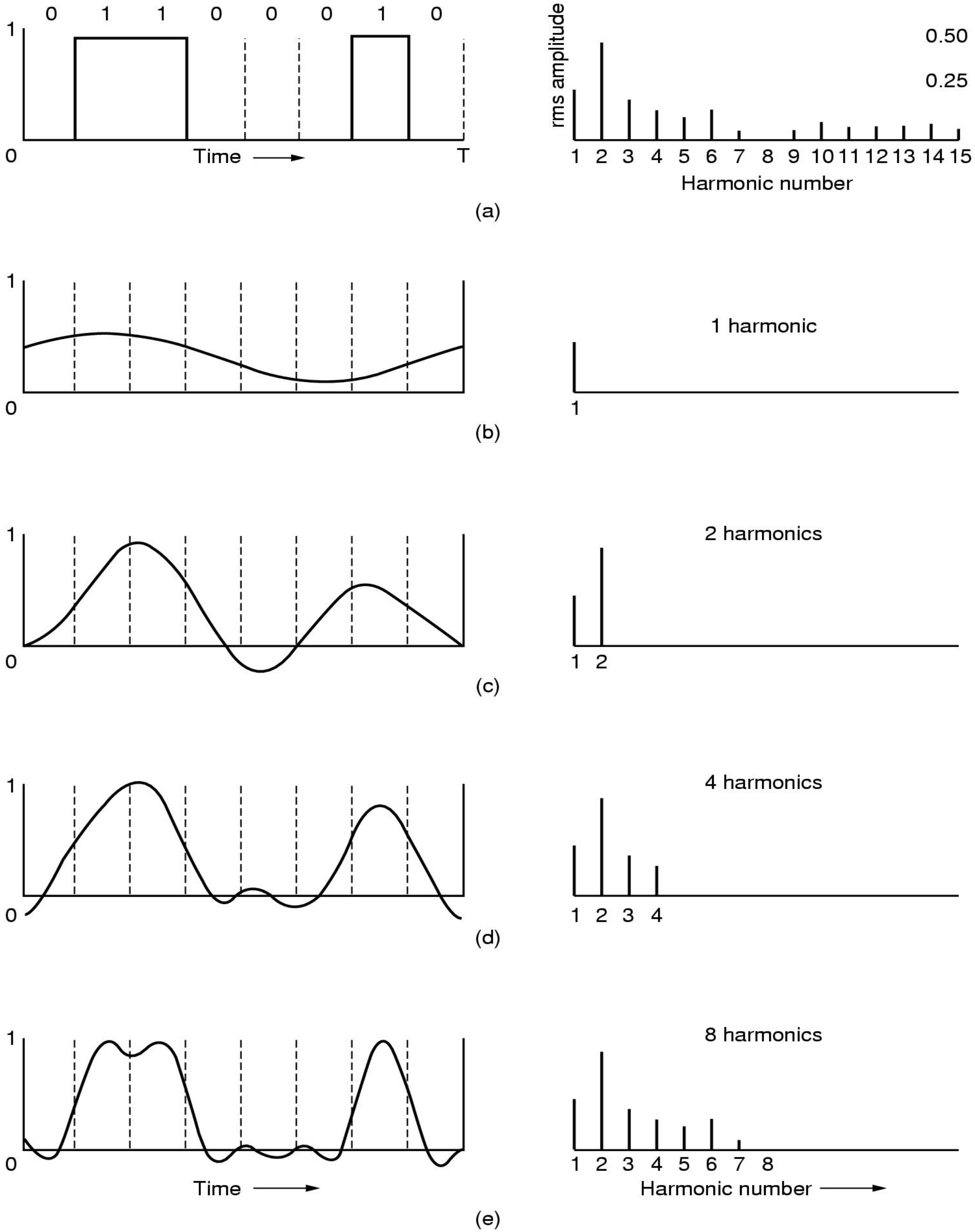
- Consider 01100010, 8 bit for ASCII character 'b':

$$a_n = 1/\pi n[\cos(\pi n/4) - \cos(3\pi n/4) + \cos(6\pi n/4) - \cos(7\pi n/4)]$$

$$b_n = 1/\pi n[\sin(3\pi n/4) - \sin(\pi n/4) + \sin(7\pi n/4) - \sin(6\pi n/4)]$$

$$c_n = 3/4$$

The root mean square amplitudes is $\sqrt{a_n^2 + b_n^2}$



Note: root mean squares (on the right) reflect the dispersed energy at the given frequency.

Bandwidth

- Digital signal transmission is subject to attenuation, distortion, etc. This is partly caused by disallowing high-frequency components to pass through.
- The range of frequency or the number of bits of a transmission medium is called **bandwidth**.

Bandwidth-Limited Signals

- The larger *n* is, the higher the frequency *nf* of the *n*th harmonic.
- All transmission facilities diminish different Fourier components by different amounts, thus introducing distortion.
- Usually, the amplitudes are transmitted undiminished from 0 up to some frequency f_c (in Hertz, Hz) with all frequencies above this cutoff frequency截止频率 strongly attenuated.

Bandwidth

- Hz
- bps
- ?

Bit Rate vs. Harmonics

- Given a bit rate of b bits/sec, the time T required to send 8 bits (for example) is $8/b$ sec, so the frequency f of the first (i.e., n=1) harmonic is $b/8$ Hz.

Bit Rate vs. Harmonics (cont.)

N	Frequency (Hz)
1	$b/8$
2	$2b/8$
:	:
n	$nb/8$

$nb/8 \le f_c$

$\Rightarrow n \le f_c / (b/8)$

- The number of the highest harmonic passed through is $f_c/(b/8)$ or $8f_c/b$, roughly. That is, the 1st, 2nd, 3rd, …, and $(8f_c/b)$-th harmonics could pass through without diminution.

Telephone Line with f_c=3000 Hz

Bit Rate (bps)	T (msec)	First Harmonic (Hz)	# Harmonics sent
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

Signal-to-Noise Ratio

- S/N
  - S: signal power
  - N: noise power
- dB
  - $10 \log_{10} S/N$
  - an S/N ratio of 1000 is 30 dB

Max. Data Rate of a Channel

- Nyquist's Theorem (noiseless channel)
  - H: bandwidth
  - V: discrete levels
  - Maximum data rate: $2H \log_2 V$ bits/sec
- Shannon's Theorem (noise channel)
  - H: bandwidth
  - S/N: signal to noise ratio
  - Maximum number of bits/sec: $H \log_2 (1 + S/N)$

Exercise

- Suppose that the bandwidth of a channel is between 3MHz and 4MHz and SN = 24dB.
  - (1) what is the capacity of this channel?
  - (2) Being able to achieve capacity, how many signaling levels are required?

Exercise solution

- Suppose that the bandwidth of a channel is between 3MHz and 4MHz and SN = 24dB.
  - (1) what is the maximum data rate?
    - H = 1MHz
    - S/N = 251
    - $C = 10^6 x\log_2(1+251)=8\text{Mbps}$
  - (2) Being able to achieve capacity, how many signaling levels are required?
    - $C=2H \log_2 V$
    - $V=16$

Presentations

- Guided transmission media/wires
- Wireless Transmission