Data Transmission

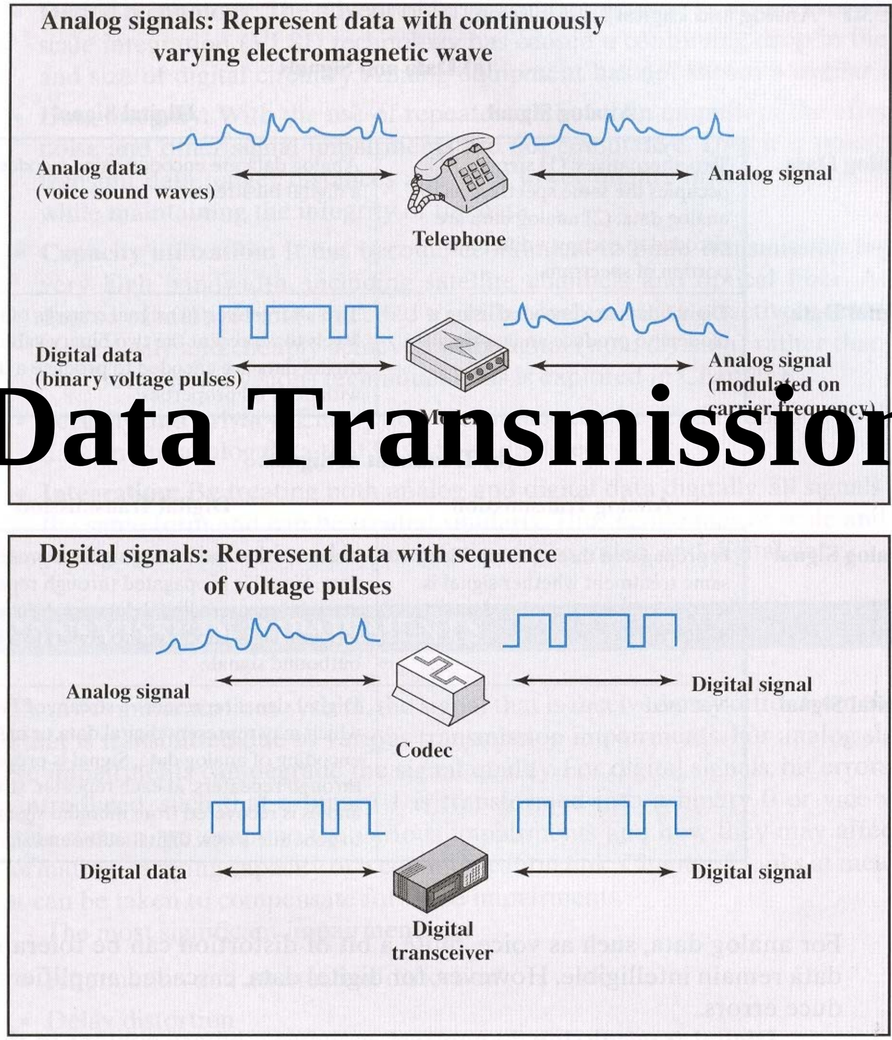


Figure 3.14 Analog and Digital Signaling of Analog and Digital Data

Contents

Data/Signal/Transmission

Data: entities that convey meaning or information

Signal: electric or electromagnetic representation of data

Transmission: processing and propagation of signals

Data

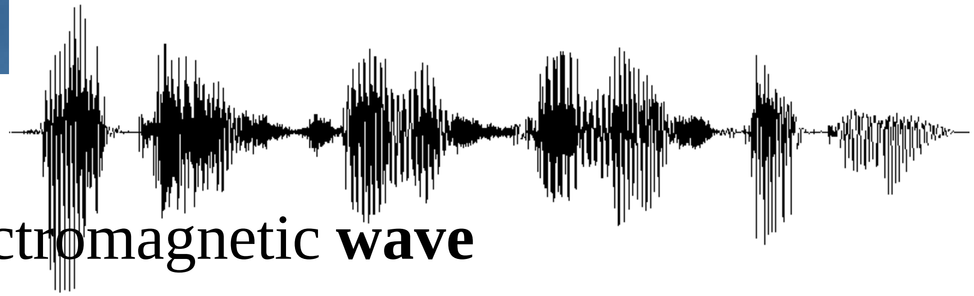
Analog data: Audio, Video

- Audio: human speech, music
- Video: TV screen

Digital data: text

- Codes are devised to represent characters by a sequence of bits
- 7-bit binary code: ASCII, CCITT Alphabet Number 5

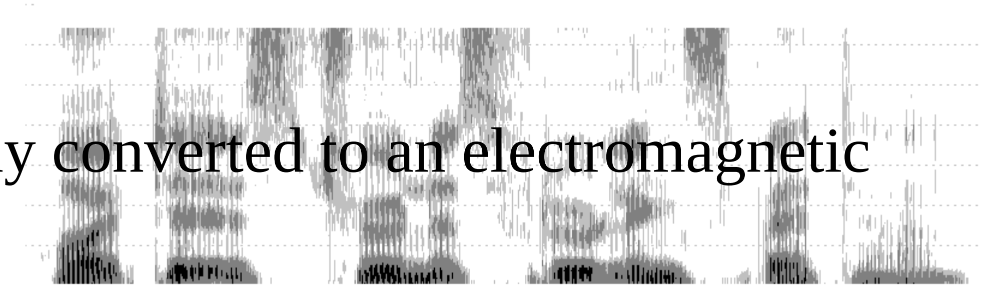
Analog Signals



A continuously varying electromagnetic **wave**

May be transmitted over wired and wireless media

Voice signals



Analog information is easily converted to an electromagnetic signal for transmission

All sound frequencies are converted into electromagnetic frequencies, whose amplitude is measured in volts

A bandwidth, the range of 300 Hz to 3400 Hz, produces acceptable voice reproduction

Analog Signals

The actual bandwidth used by telephone transmission facility is 4 kHz, not 3.1 kHz

The extra bandwidth serves the purpose of isolating the sound signal from interference from signals in adjacent bandwidth

Analog Signals

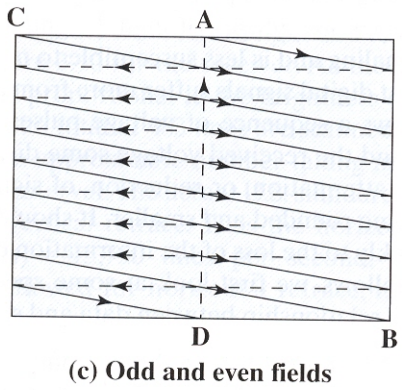


Figure 3.10 Video Interlaced Scanning

Video signals

To produce a picture on the screen, an electronic beam scans across the surface of the screen from left to right and top to bottom

At any instant in time the beam takes on an analog value of intensity to produce the desired brightness at that point on the screen

To transmit analog video information at the necessary rate, a bandwidth of about 4 MHz is needed

The standard bandwidth for color video signaling is 6 MHz

Digital Signal

- A sequence of voltage **pulses**
  - e.g. constant positive voltage: 0, constant negative voltage:
- May be transmitted over a **wired medium**
- The numbers or text which is converted into binary form is converted into a digital signal

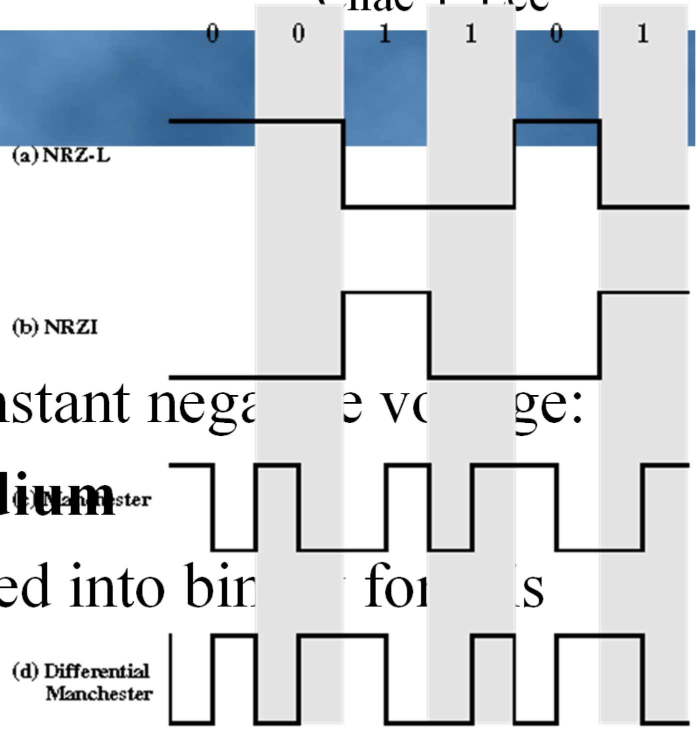


Figure 5.5 Examples of Digital Signal Encoding Schemes

Signal

Sign wave: a fundamental periodic signal

- amplitude
- **frequency**
- period
- phase

$s(t) = A \sin(2\pi ft + \phi)$

wave length (λ): the distance occupied by a single cycle

- $\lambda = vT$, $\lambda f = v$
- $v = c = 3 \times 10^8$ m/s

Signal

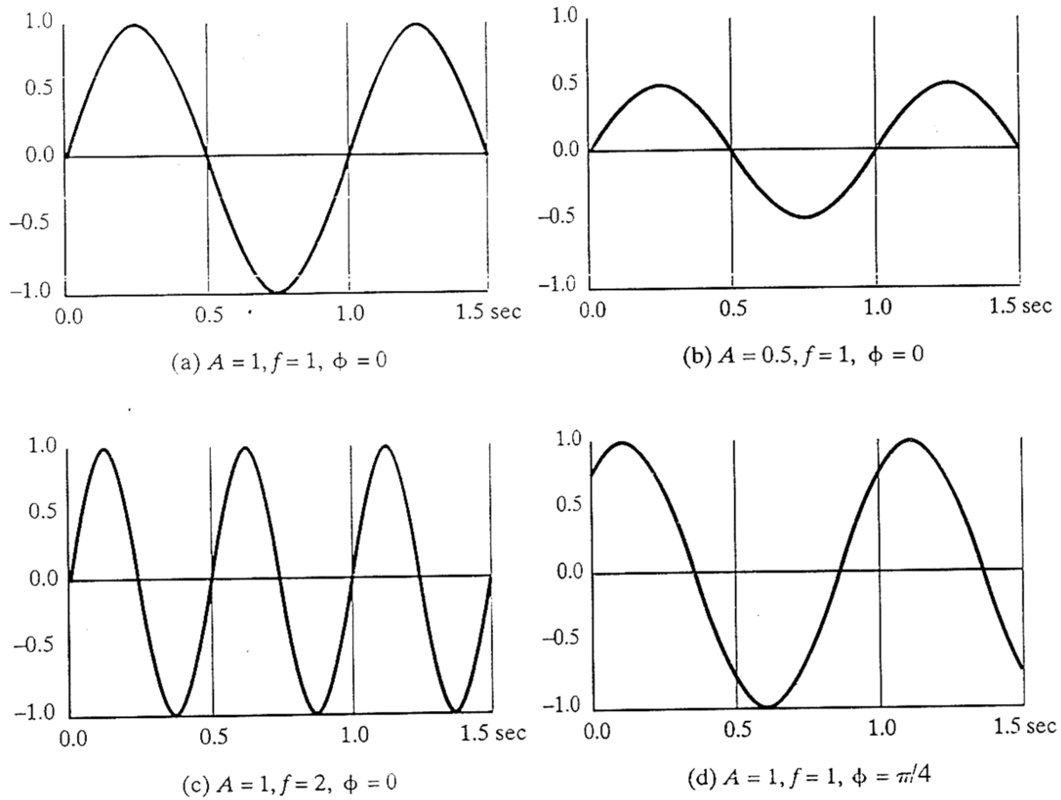


FIGURE 1 $A \sin(2\pi ft + \phi)$.

Frequency, Spectrum and Bandwidth

$s(t) = \sin(2\pi f_1 t) + 1/3 \sin(2\pi(3f_1)t)$

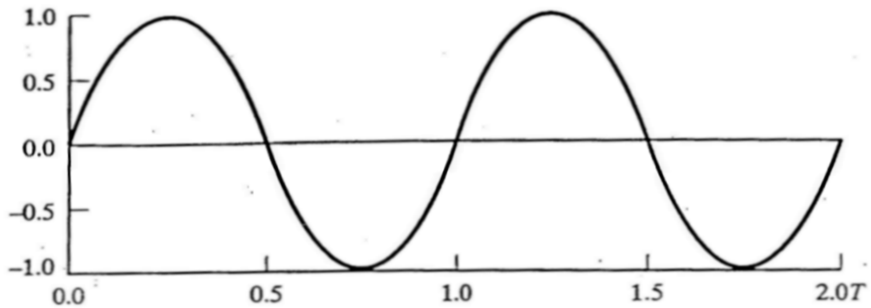
fundamental frequency: f_1

The period of the total signal is equal to the period of the fundamental frequency

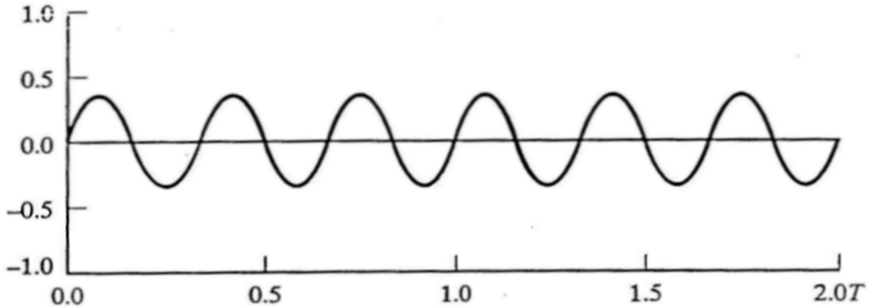
By adding together enough signals any electromagnetic signal can be constructed

Spectrum of a signal: range of frequencies that it contains

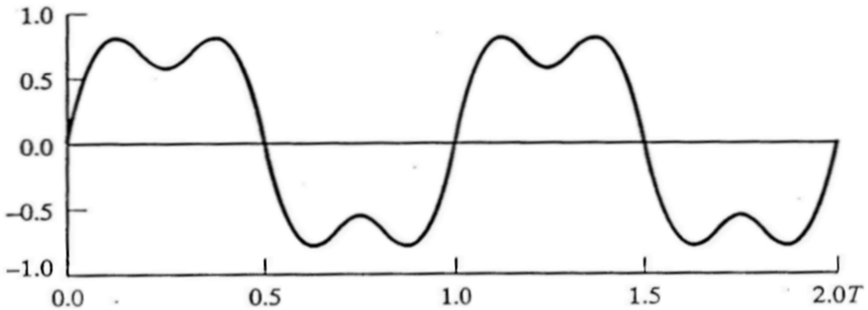
Bandwidth: width of the spectrum



(a) $\sin(2\pi f_1 t)$



(b) $\frac{1}{3}\sin[2\pi(3f_1)t]$



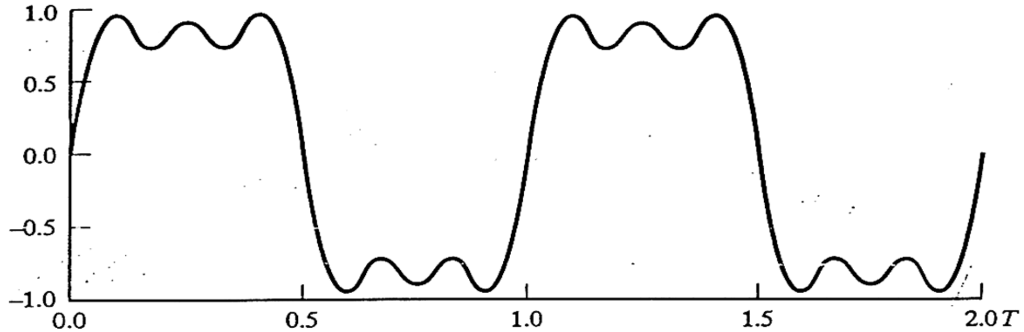
(c) $\sin(2\pi f_1 t) + \frac{1}{3}\sin[2\pi(3f_1)t]$

FIGURE 2 Addition of Frequency Components ($T = 1/f_1$).

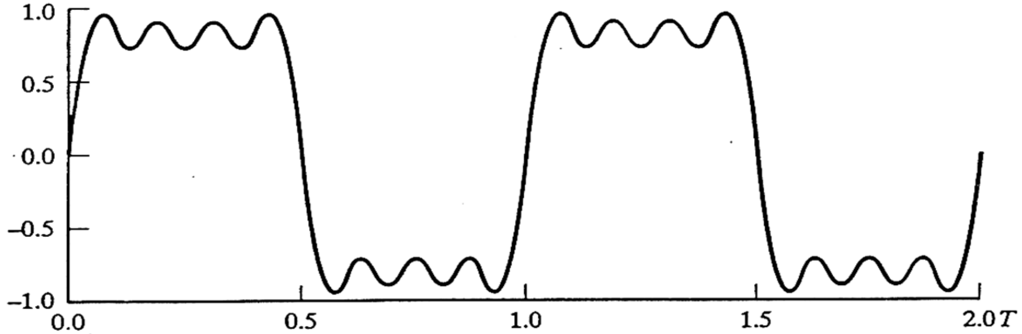
Bandwidth

Bandwidth and the quality of digital signal

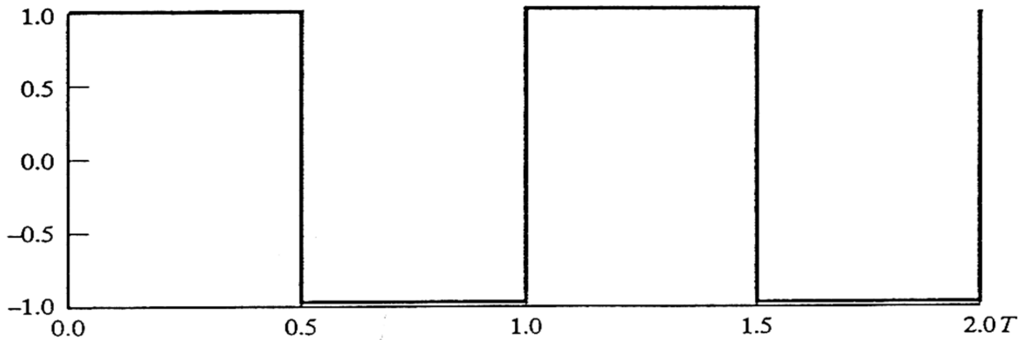
- The ideal digital signal with nice sharp corners actually requires infinite bandwidth
- The greater the bandwidth of the signal, the more faithfully it approximates a digital pulse stream
- The greater the bandwidth, the higher the information-carrying capacity
- By adding additional odd multiples of f_1, the resulting wave form approaches that of a square wave more and more closely



(a) $\sin(2\pi f_1 t) + \frac{1}{3}\sin[2\pi(3f_1)t] + \frac{1}{5}\sin[2\pi(5f_1)t]$



(b) $\sin(2\pi f_1 t) + \frac{1}{3}\sin[2\pi(3f_1)t] + \frac{1}{5}\sin[2\pi(5f_1)t) + \frac{1}{7}\sin[2\pi(7f_1)t]$



(c) $\Sigma(1/k)\ \sin[2\pi(kf_1)t]$

FIGURE 3 Frequency Components of a Square Wave ($T = 1/f_1$).

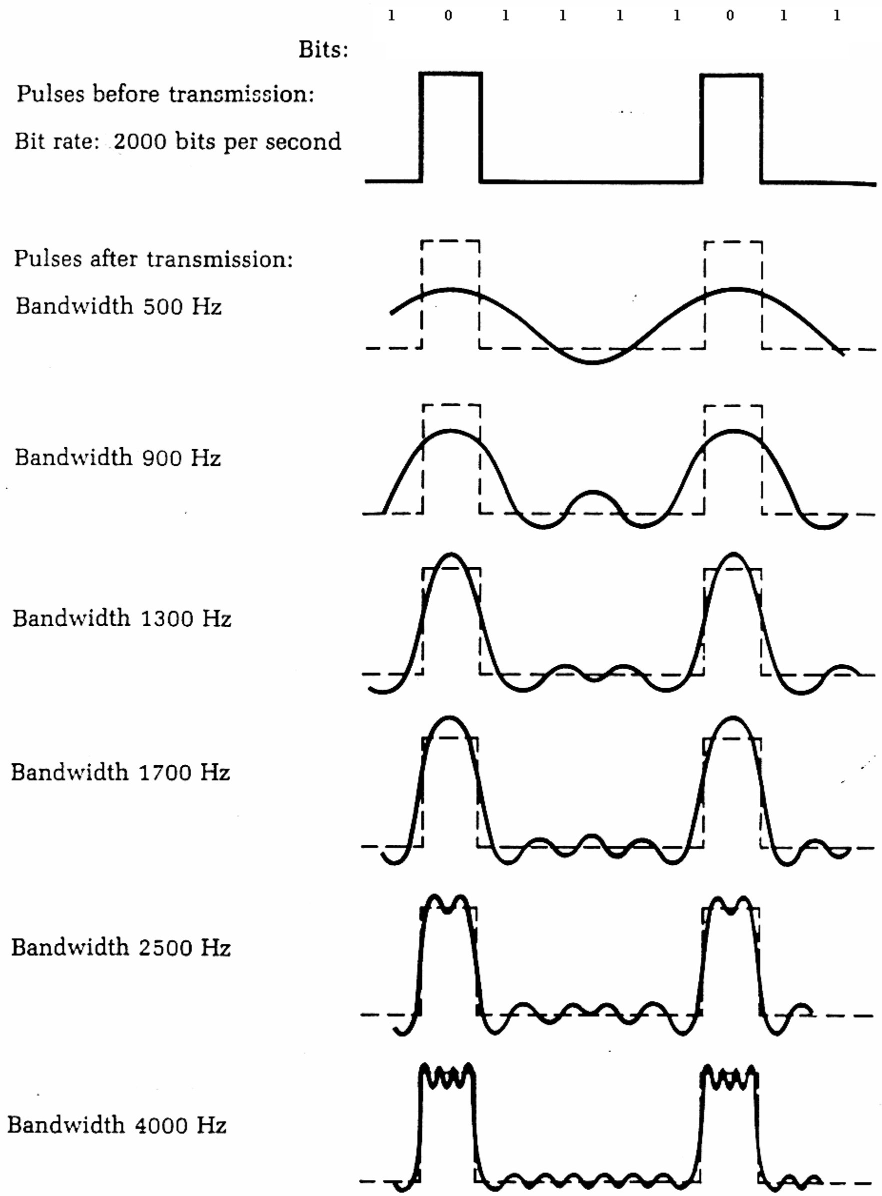


FIGURE 4 Effect of Bandwidth on a Digital Signal

Data Rate and Bandwidth

The Frequency components of the square wave can be expressed as

$s(t) = A \Sigma 1/k \sin(2\pi k f_1 t)$

Transmitting signals with a bandwidth of 4MHz

f_1 = 1MHz f_1 , $3f_1$, $5f_1$

T = 10^{-6} = 1 μsec

One bit occurs every 0.5 μsec

Data rate of 2 x 10^6 = 2Mbps

For a bandwidth of 4 MHz, a data rate of 2 Mbps is achieved

Data Rate and Bandwidth

Transmitting signals with a bandwidth of 8MHz

- f_1 = 2MHz f_1, $3f_1$, $5f_1$
- T = 0.5 μsec
- One bit occurs every 0.25μsec
- Data rate of 4Mbps
- **By doubling the bandwidth, the potential data rate is doubled**

Data Rate and Bandwidth

General conclusion

For any given medium, the greater the bandwidth transmitted, the greater the cost

Digital information can be approximated by a signal of limited bandwidth

The more limited the bandwidth, the greater the distortion, and the greater the potential for error by the receiver

Transmission services

Encoding the information into an electromagnetic signal

Inserting a signal on the medium: **modulation**

Interface between a device and the transmission medium

Controlling the flow of information

Recovering from its loss and corruption

Transmission

Analog Transmission:

Tx analog signals without regard to their content
Attenuation after a certain distance
Amplifier to boost the signal
Amplifier also boosts noise

Digital Transmission:

Tx of digital signal or analog signal that carries digital data
Repeaters are used for greater distance
Repeater recovers the digital data from the analog signal and generates new one

The trend in telecommunications is a gradual conversion from analog to digital conversion

Transmission Impairments

Attenuation

An electromagnetic signal is gradually becomes weaker at greater distances

Amplifiers or repeaters are used for a signal with sufficient strength

An amplifier is used for analog signals

A repeater is used for digital signals

Attenuation is greater at higher frequencies and this causes distortion

Attenuation distortion is noticeable in analogue signals

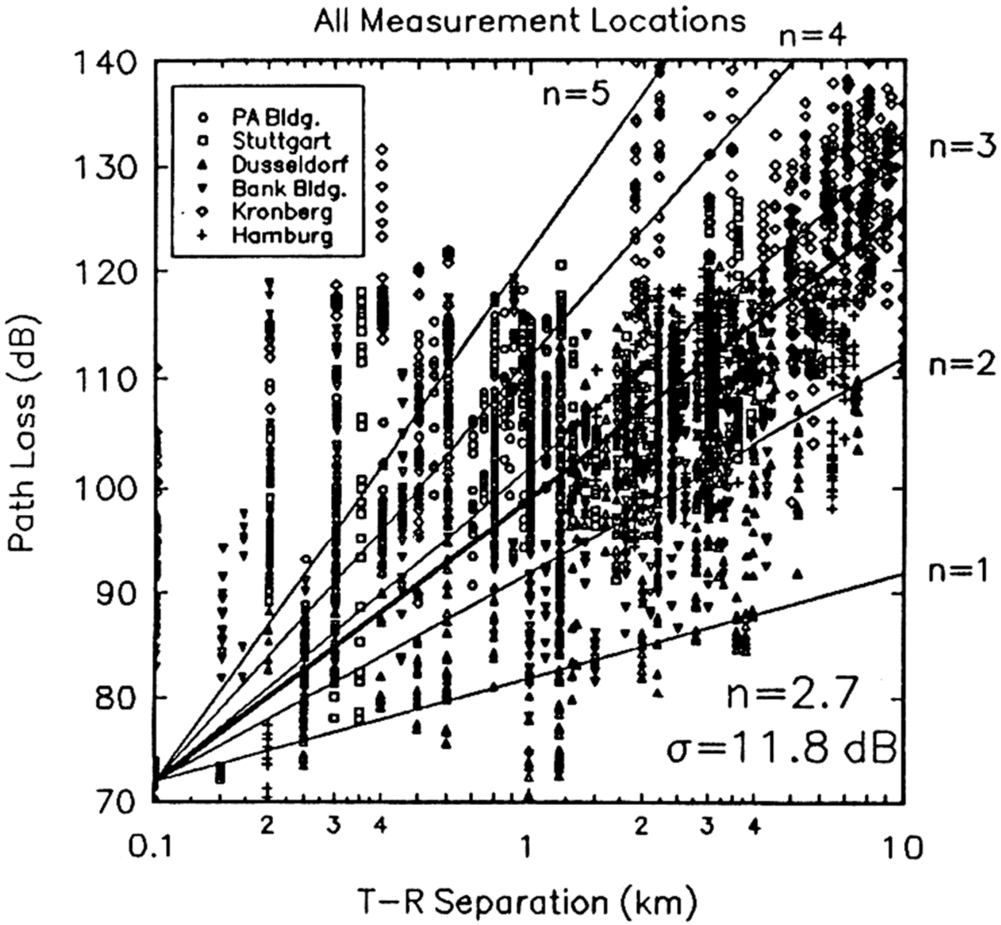


Figure 3.17
Scatter plot of measured data and corresponding MMSE path loss model for six cities in Germany. For this data, $n = 2.7$ and $\sigma = 11.8$ dB [From [Sei91] © IEEE].

Transmission Impairments

Delay Distortion

The velocity of propagation of a signal through a cable is different for different frequencies

Various frequency components of a signal arrives at the receiver at different times

Some of the signal components of one bit position spill over into other bit position: inter-symbol interference (ISI)

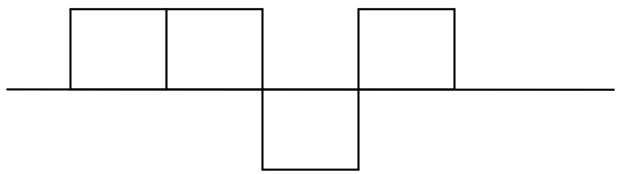
Delay distortion is particularly critical for digital data

Equalization can be used to correct the delay distortion

Transmission Impairments

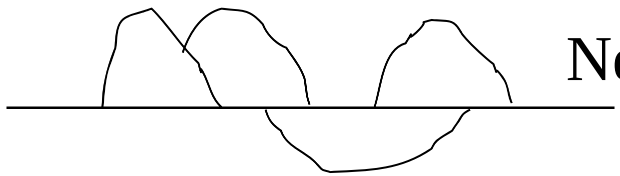
Delay Distortion

Ideal



No delay spread

Practical



Need to reduce the delay spread

Delay Spread in Wireless Media

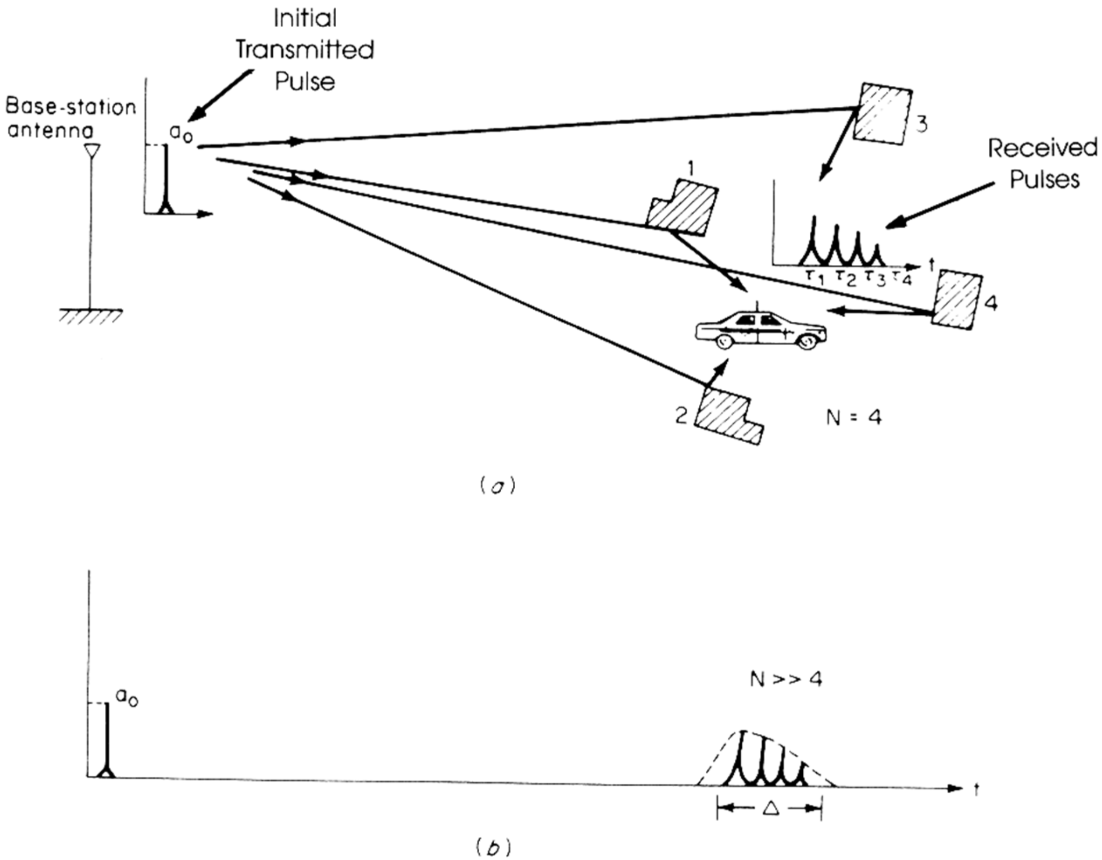


Figure 8.14 Illustration of Delay Spread.

Source: William C.Y. Lee, *Mobile Communications Engineering*, p.40.

Delay Spread in Wireless Media

- Due to multipath, several copies of signals are received
- Differences in arrival times caused by the multipath environment
  - Signals are spread out over time
  - It depends on the environment
    - Indoor < 1μsec
    - Rural environment: few μsec
    - Urban building: 10 μsec

Delay Spread in Wireless Media

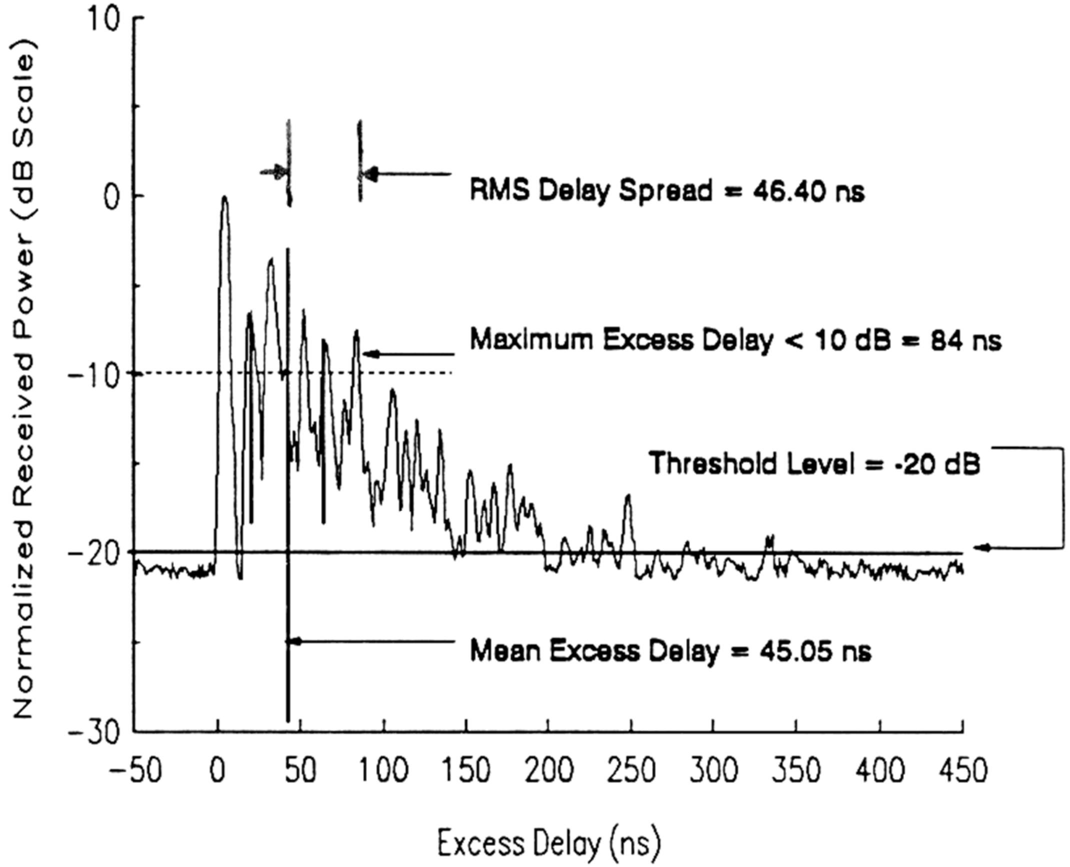


Figure 4.10
Example of an indoor power delay profile; rms delay spread, mean excess delay, maximum excess delay (10 dB), and threshold level are shown.

Transmission Impairments

Noise

The unwanted electromagnetic energy that is inserted somewhere between transmission and reception

Four categories:

1. Thermal noise
2. Intermodulation noise
3. Crosstalk
4. Impulse noise

Transmission Impairments

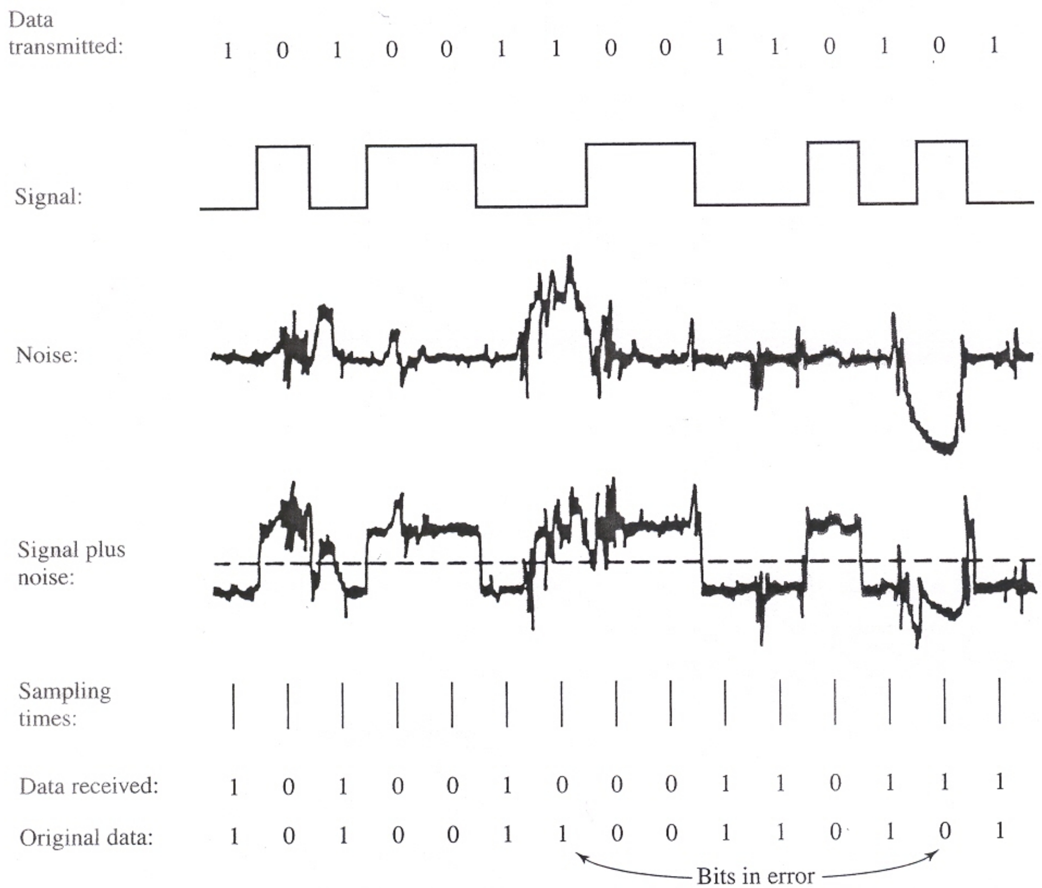


Figure 3.16 Effect of Noise on a Digital Signal

Transmission Impairments

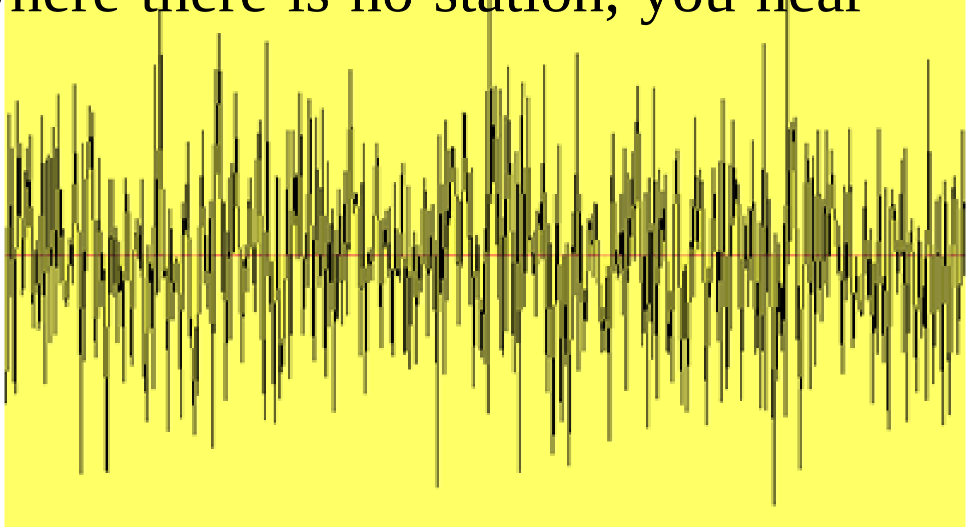
Thermal noise

Results from thermal agitation of electrons in a conductor

Present in all electronic devices and transmission media as a function of temperature

In the FM broadcast band where there is no station, you hear the hiss in the background

Cannot be eliminated



Transmission Impairments

Intermodulation noise

Results when signals of different frequencies share the same transmission medium

Produces signals at a frequency that is the sum $f_1 + f_2$ or difference $f_1 - f_2$ of the two original frequencies or multiples of those frequencies $2f_1 - f_2$ or $2f_2 - f_1$

Someone listening to a car radio while driving close by an AM or FM radio transmission tower may hear two types of 'interference' / distortion:

✓'break-through', where the transmission from the near station overwhelms the car radio; and

✓intermodulation, where another station entirely is heard

Transmission Impairments

Crosstalk

An unwanted coupling between signal paths

Electrical coupling between nearby cables or by the overlap of signals transmitted by antennas

Impulse noise

Consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude

Generated from lightning and faults and flaws in the communications system

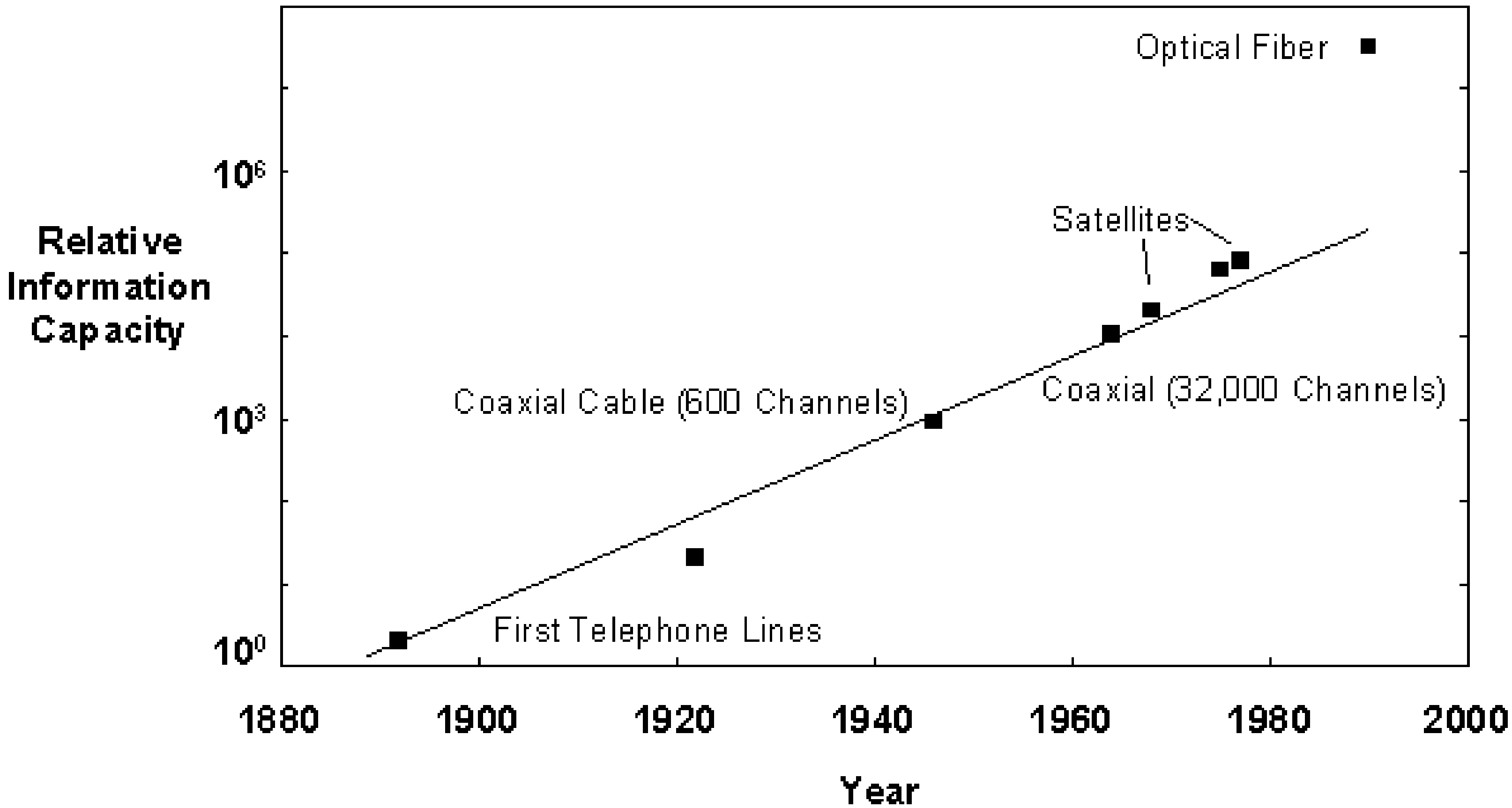
The primary source of error in digital data communication

Channel Capacity

The rate at which data can be transmitted over a given communication path, or channel

Data rate
Bandwidth
Noise
Error rate

Channel Capacity



Channel Capacity

All Tx channels are of limited bandwidth

The limitations arise from the physical properties of transmission medium or from deliberate limitations at the transmitter on the bandwidth to prevent interference from other sources

Doubling the bandwidth doubles the data rate

If the data rate is increased, then the bits become "shorter", so that more bits are affected by a given pattern of noise

At a given noise level, the higher the data rate, the higher the error rate

Channel Capacity

The signal-to-noise ratio (S/N):
Ratio of the power of a signal to the power of the noise that is present at a particular point in the transmission

The maximum channel capacity obeys the equation by Shannon:

$$C = BW \log_2 (1 + S/N)$$

Channel Capacity

In practice, only much lower rates are achieved

The formula assumes white noise (thermal noise)

By Shannon's capacity theorem the capacity of a typical PSTN channel with a band-limited signal of 3100Hz (300-3400Hz) and a 30dB S/N becomes

$C = 3100 \log_2 (1 + 1000) = 31{,}000$ bps

In the PSTN a bit rate of 9600 bps has been about the practical limits

In today's network some voice grade channels can carry 19.2 kbps and in a few cases even more

Channel Capacity

Theoretical transmission efficiency

For a given level of noise, the data rate could be increased by increasing the signal strength or the bandwidth

Since noise is assumed to be white, the wider the bandwidth, the more noise is admitted to the system

Signal Strength

As a signal propagates along a transmission medium, there will be a loss, or attenuation of signal strength

To compensate, amplifiers may be inserted at various points to impart a gain in signal strength

It is customary to express gains, losses, and relative levels in decibels because:

Signal strength often falls off logarithmically, so loss is easily expressed in terms of the decibel, which is logarithmic unit

Gains and losses in a cascaded transmission path can be calculated with simple addition and subtraction

$$N_{dB} = 10 \log_{10} (P_1/P_2)$$

Signal Strength

Example: If a signal with a power of 10 mw is inserted onto a transmission line and the measured power some distance away is 5 mw, the loss becomes

LOSS = 10log(5/10) = 10(-0.3) = -3 dB

The decibel is a measure of relative, not absolute, difference
A loss from 1000 w to 500 w is also a -3dB loss

Signal Strength

An absolute level of power or voltage in decibels

Power (dBW) = 10 log (Power(W)/1W)
Power (dBm) = 10 log (Power(mW)/1mW)

A power of 1000w is 30 dBW
A power of 1 mw is -30 dBW

Signal Strength

The decibel is also used to measure the difference in voltage, taking into account that power is proportional to the square of voltage:

$P = V^2/R$

$N_{dB} = 10 \log (P_1/P_2) = 20 \log (V_1/V_2)$

Voltage(dBmV) = 20 log (Voltage(mV)/1mV)

Power in dB

$$10\ log_{10}X = x\ dB$$

X	x (dB)
1	0
2	3
3	5
5	7
10	10
20	13
100	20

$x\ dB = 10\ log_{10}X$

$dBW = 10\ log_{10}P$ (watt)

$dBm = 10\ log_{10}P$ (mW)

(1W = 1000mW = 30dBm)

Laws of dB

1. dB $\pm$ dB = dB
2. dBm - dBm = dB
3. dBm $\pm$ dB = dBm

Summary

Analog/Digital signals

Frequency, spectrum and bandwidth

Transmission impairments:

noise, attenuation, delay distortion

Channel capacity

$$C = BW \log_2 (1 + S/N)$$