Computer Networks 1

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TRANSMISSION IMPAIRMENTS

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TRANSMISSION IMPAIRMENTS

- Received signal is often a degraded form of the transmitted signal
- Why?
  - Attenuation
  - Distortion
  - Noise
  - Interference
- Effect:
  - On analog data
    - Some degradation in signal quality
  - On digital data
    - Fatal bit errors

SIGNAL POWER IN DECIBELS

$$10\log_{10}(P_{watt}) = P_{dB}$$

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

- Example: $P=1\ W$
  - P_{dB}=?
  - P_{dBm}=?

SIGNAL POWER IN DECIBELS

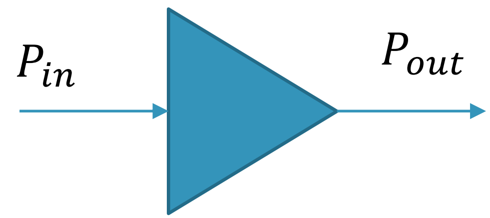
$$10\log_{10}(P_{watt}) = P_{dB}$$

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

- Example: *P=1 W*
  - P_{dB}=0 dB
  - P_{dBm}=30 dBm

POWER RATIO IN DECIBELS

$$G = \frac{P_{out}}{P_{in}}$$



$$G_{dB} = 10\log_{10} G = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

$G = 2 \qquad G_{dB} = ?$

$G = 1/2 \qquad G_{dB} = ?$

OUTLINE

Attenuation

Distortion

Noise

OUTLINE

Attenuation

Distortion

Noise

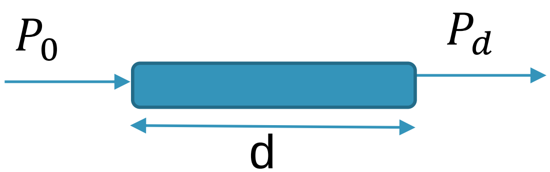
ATTENUATION

- Signal strength falls off with distance traveled
  - Guided Media (Wires, etc.):
    - Exponential drop in signal power with distance:

$$P_d = P_0 \, e^{-\alpha d}$$

$$ln\left(\frac{P_d}{P_0}\right) = -\alpha d$$

$$10 \log\left(\frac{P_d}{P_0}\right) = -\alpha' d$$



Loss: α' (dBs per km) (Depends on medium type)

ATTENUATION

- Unguided Media (Open space):
  - Depends on
    - Absorption, scattering, weather
  - Inverse square law spread with distance

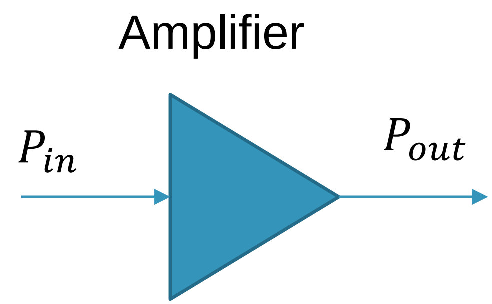
$$P_d \propto \frac{P_0}{d^2}$$

Loss: 6 dBs for each distance doubling

LINK BUDGET

$$G = \frac{P_{out}}{P_{in}} \qquad G_{dB} = 10\log(\frac{P_{out}}{P_{in}})$$

$$(P_{in})_{dB} + G_{dB} = (P_{out})_{dB}$$



$$L = \frac{P_{in}}{P_{out}} \qquad L_{dB} = 10\log\frac{P_{in}}{P_{out}}$$

$$(P_{in})_{dB} - L_{dB} = (P_{out})_{dB}$$

DESIGN ISSUES RELATED TO ATTENUATION

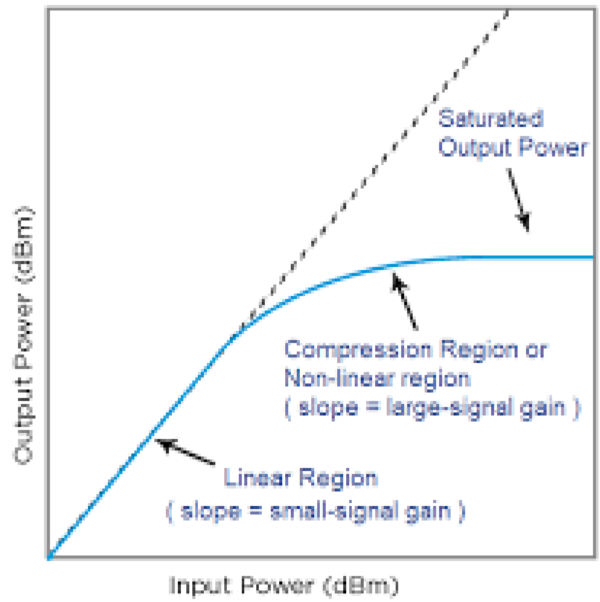
- Received signal strength must be
  - Sufficiently Large enough to be detected
  - Sufficiently higher than noise to be interpreted correctly

$$(P_{out\_Tx})_{dB} - L_{dB} > (P_{s\_Rx})_{dB}$$

- Design Key parameters
  - Transmitted Power
  - Channel Loss
  - Receiver Sensitivity

TRANSMITTED POWER

- Increasing transmitted power
  - Power amplifier gains should not be too large



Nonlinearities → Saturation → Signal distortion

RECEIVER SENSITIVITY

- Increasing receiver sensitivity
  - Decreasing minimum receivable power
  - Bad news: Noise

CHANNEL ATTENUATION

- Limited distance
  - To overcome these issues using
    - Amplifiers (analog transmission)
    - Repeaters (digital transmission)

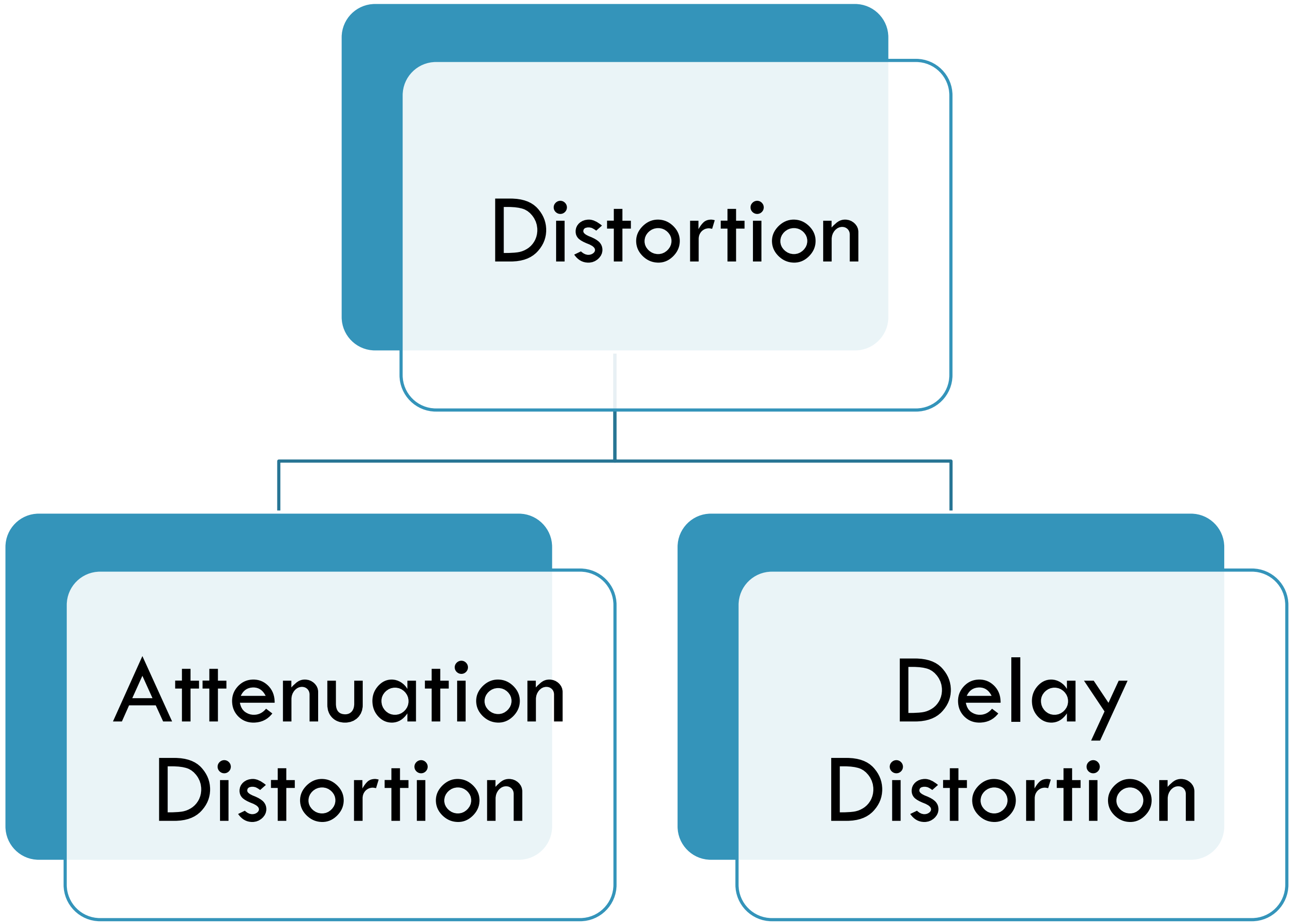
OUTLINE

Attenuation

Distortion

Noise

DISTORTION



DISTORTION

- Distortion
  - Attenuation Distortion
  - Delay Distortion

ATTENUATION DISTORTION

- Attenuation varies with frequency
  - Causes bandwidth limitation
- In the transmitted bandwidth
  - Different Attenuation for frequency components of the signal
  - Causes signal distortion
  - Affects analog signals more
- To overcome this problem
  - Use Equalizers
    - Reverse the effect of frequency-dependent attenuation distortion

EQUALIZER

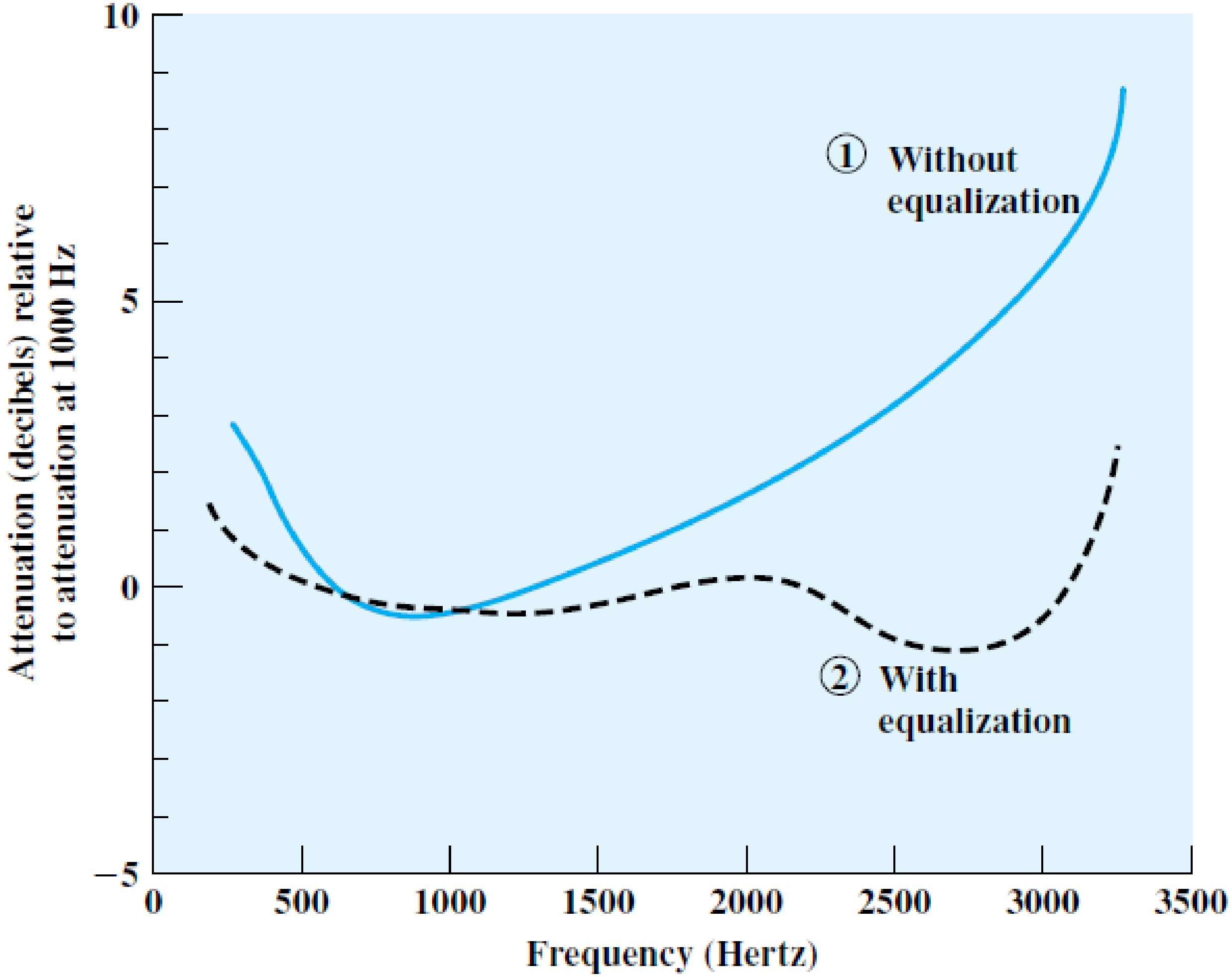
- Passive
  - Smooth out attenuation effects
    - Loading coils in telephone circuits
    - Change the electrical properties of the line
- Active
  - Designing amplifier gain specifically
  - Varying with frequency
  - Reversing channel characteristics

ATTENUATION AS A FUNCTION OF FREQUENCY

- Measuring attenuation relative to the attenuation at 1000 Hz
  - A 1000-Hz tone of a given power is applied to the input
  - The power P_{1000} is measured at the output
  - For any frequency *f*, the procedure is repeated $\rightarrow Pf$
- Relative attenuation in decibels

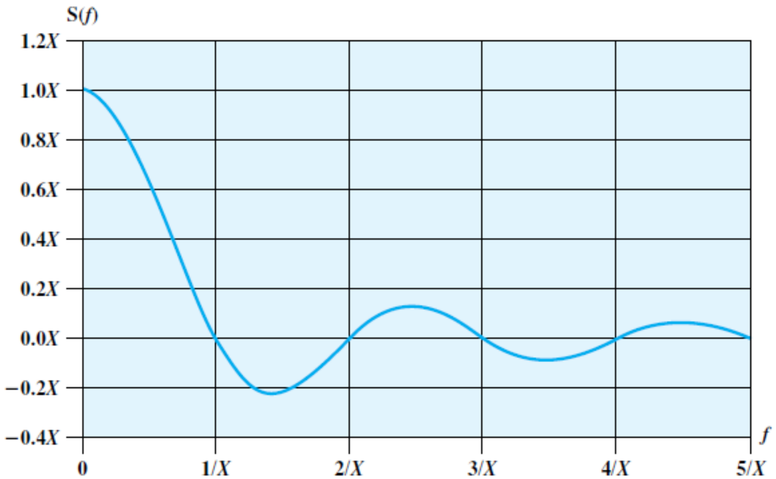
$$N_f = -10\, log(Pf/P_{1000})$$

EQUALIZATION EFFECT ON ATTENUATION DISTORTION



ATTENUATION DISTORTION OF DIGITAL SIGNAL

- The strength of a digital signal falls off rapidly with frequency
  - Most of the content concentrated near the fundamental frequency
- Less problem for digital signals



(b) $s(t) = 1 \qquad -X/2 \leq t \leq X/2$

DISTORTION

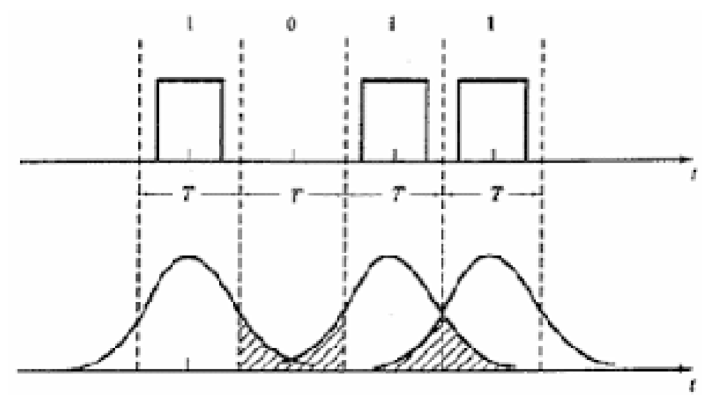
- Distortion
  - Attenuation Distortion
  - Delay Distortion

DELAY DISTORTION

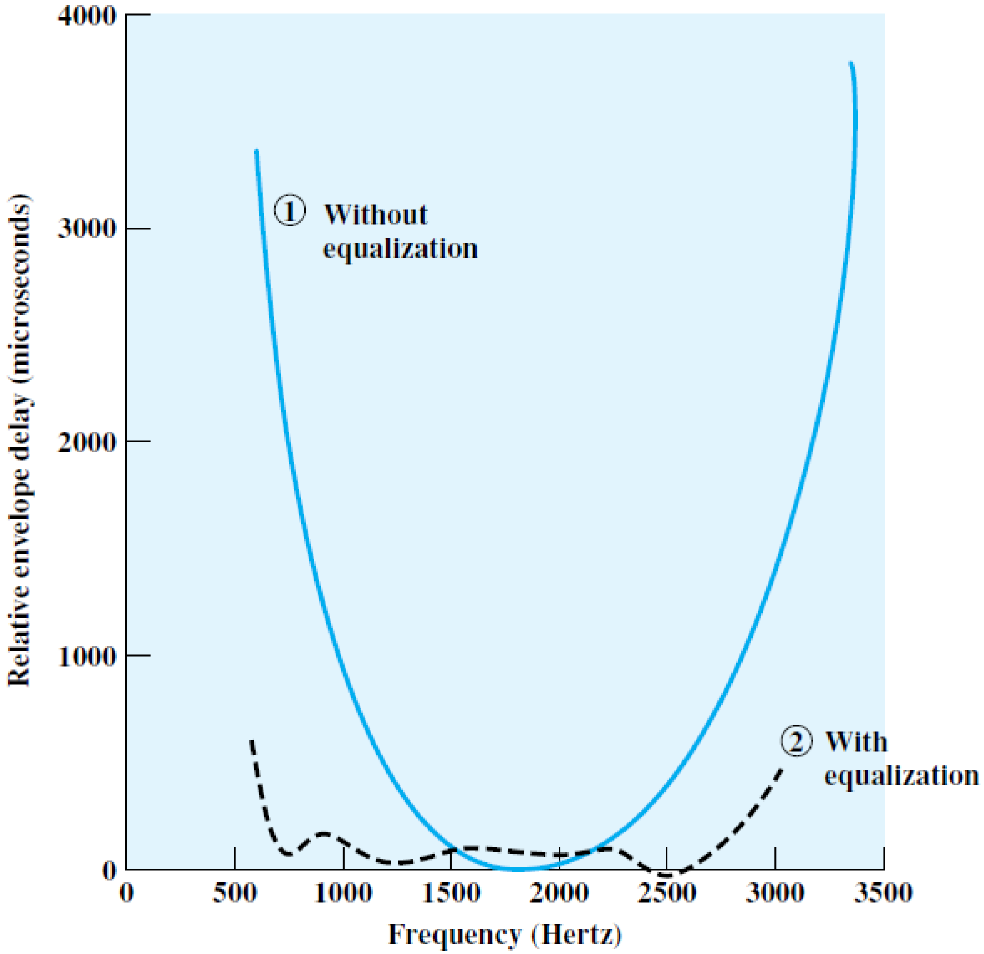
- Happens only on guided media
- Wave propagation velocity varies with frequency
  - Highest at the center frequency (minimum delay)
  - Lower at both ends of the bandwidth (larger delay)
- Various frequency components of a signal
  - Arrive at the receiver at different times
  - Experience different delays
- Received signal is distorted
- Solution
  - Equalizing techniques

DELAY DISTORTION FOR DIGITAL DATA

- Critical for digital data
  - Carrying by analog or digital signals
- Inter-symbol interference (ISI)
  - Delay distortion
  - Signal components of one bit position will spill over into other bit positions
  - Major limitation to maximum bit rate over a channel



EQUALIZATION EFFECT ON DELAY DISTORTION



OUTLINE

Attenuation

Distortion

Noise

NOISE

- Any additional unwanted signal
- Inserted between transmitter and receiver
- The most limiting factor in communication systems
- Noise Types
  - Thermal (White) Noise
  - Inter-modulation Noise
  - Impulse Noise
  - Crosstalk Noise

THERMAL NOISE

- Due to thermal agitation of electrons
- Increases with temperature
- White noise
  - Uniformly distributed over frequency
  - Exists even in the same bandwidth as the signal
  - Difficult to eliminate
- More significant effect on weak received signals
  - Satellite communication

THERMAL NOISE

- White noise
  - Uniformly distributed over frequency
- Noise Power Spectral Density

$$N_0 = kT \quad \text{(W/Hz)}$$

k: Boltzmann's constant, $k = 1.38 \times 10^{-23}\, J/°K$

T: Absolute temperature in Kelvin

- Noise Power in Bandwidth B Hz

$$N = N_0 B = kTB \quad \text{(Watts)}$$

INTER-MODULATION NOISE

- When signals with various frequencies sharing a transmission system
- Caused by nonlinearities in the medium and equipment
- Resulting new frequency components within valid signal bands

INTER-MODULATION NOISE EXAMPLE

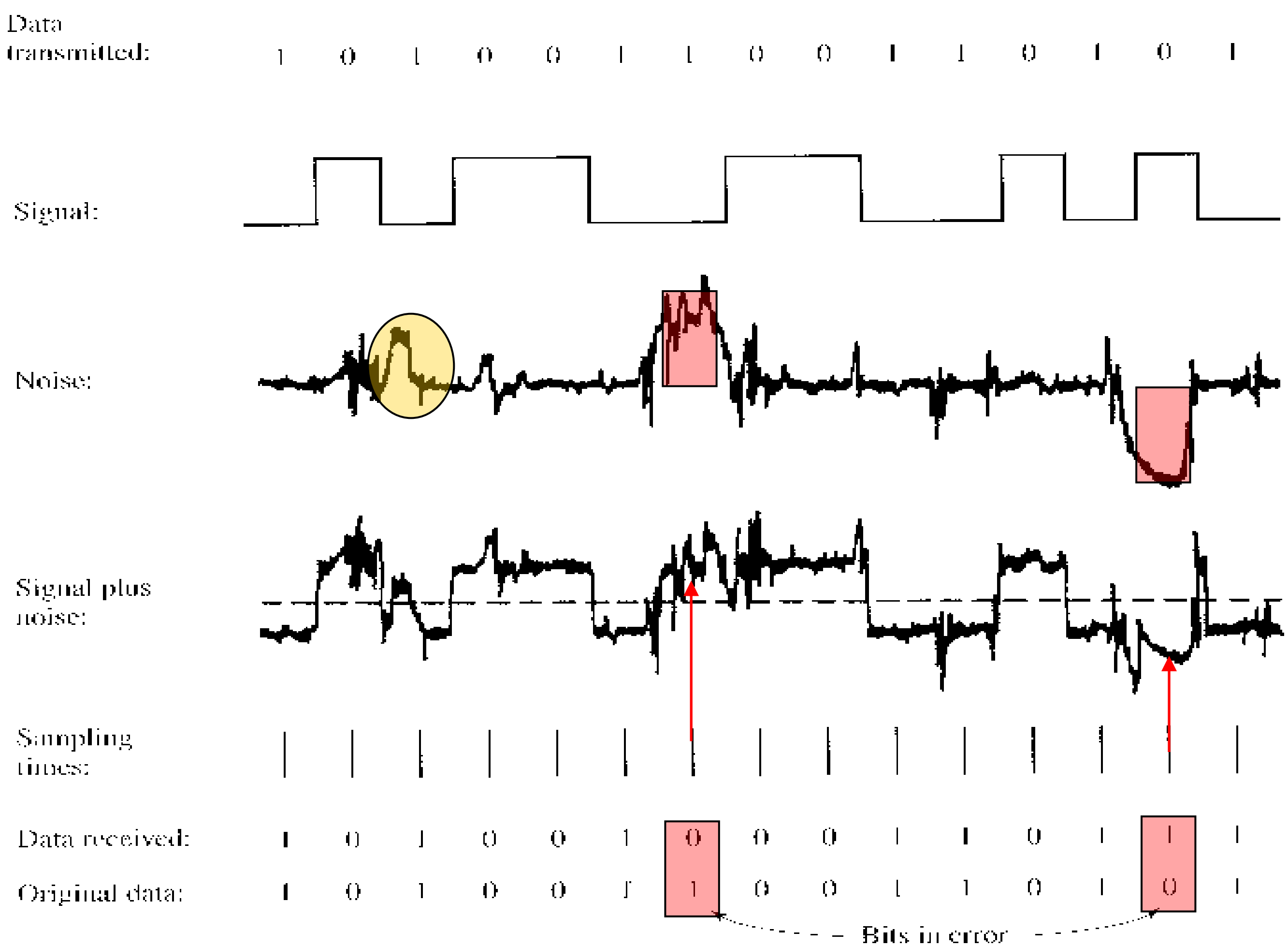
$$x(t) = \cos(2\pi f_1 t) + \cos(2\pi f_2 t)$$

$$y(t) = a_1 x(t) + a_2 x^2(t) + a_3 x^3(t) + \cdots$$

IMPULSE NOISE

- Pulses (spikes) of
  - Irregular shape
  - High amplitude
  - Lasting short durations
- Causes
  - External electromagnetic interference
    - Due to switching large currents, lightning, …
- Minor effect on analog signals
  - e.g. crackling noise in voice channels
- Major effect on digital signals
  - Bit reversal error
- More damage at higher data rates
  - A noise pulse of a given width can destroy a larger block of bits

IMPULSE NOISE ON A DIGITAL SIGNAL



CROSSTALK NOISE

- A signal from one channel picked up by another channel in close proximity
- Examples
  - Physical proximity
    - coupling between adjacent twisted pair channels
    - Shield cables properly
  - Directional proximity
    - Antenna pick up from other directions
    - Use directional antennas
  - Spectral proximity
    - Leakage between adjacent channels in frequency division multiplexing (FDM) systems
    - Use guard bands between adjacent channels