# Data Transmission

ITS323: Introduction to Data Communications

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# Transmission Terminology

- Data transmission occurs between a transmitter and receiver via some medium
- Communication is in form of electromagnetic waves
- Medium may be:

  **Guided:** wires/cables, e.g. twisted pair, coaxial cable, optical fiber

  **Unguided:** wireless, e.g. air, water, vacuum
- Configuration may be:

  **Point-to-point:** only 2 devices share medium

  **Multipoint:** more than 2 devices share medium
- Direction of communications may be:

  **Simplex:** one direction, e.g. television

  **Half duplex:** either direction, but only one way at a time, e.g. police radio

  **Full duplex:** both directions at the same time, e.g. telephone

# Frequency, Spectrum and Bandwidth

- Transmitter generates electromagnetic signals, which is transmitted over medium
- Electromagnetic signals represent data
- Electromagnetic signal consists of one or more component signals
- Electromagnetic signals can be viewed in two domains:

  **Time domain:** signal intensity vs time

  **Frequency domain:** Peak signal intensity of component vs frequency

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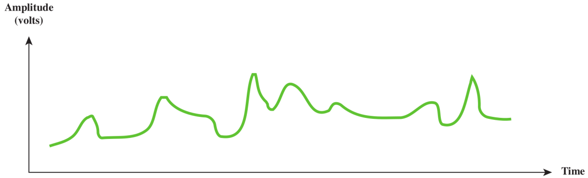
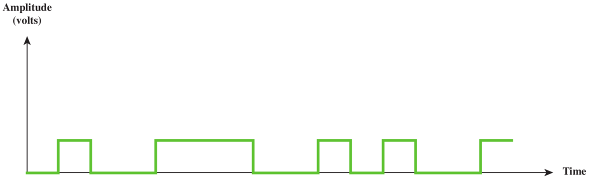
# Analog and Digital Waveforms




(a) Analog

Analog signal varies in continuous manner over time

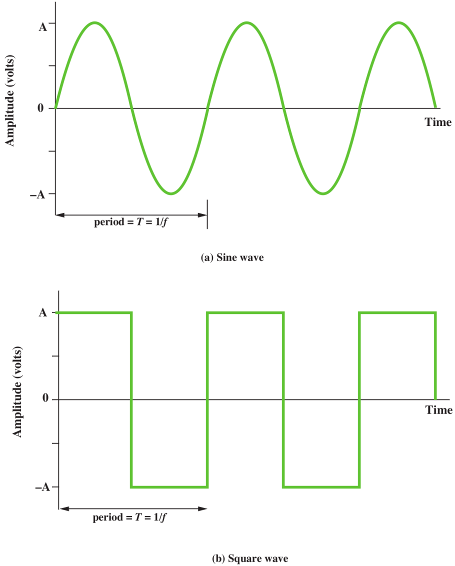



(b) Digital

Digital signal maintains constant level for some period then changes to another constant level, in a discrete manner

# Examples of Periodic Signals

Any signal is either periodic (the following two) or aperiodic



# Sinusoid Signals

- Sine wave is the fundamental periodic signal

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

- Communication signals are made up of sinusoid signals

  **Peak amplitude, $A$:** maximum strength of signal over time [volts]

  **Frequency, $f$:** rate at which signal repeats [cycles per second or Hertz]

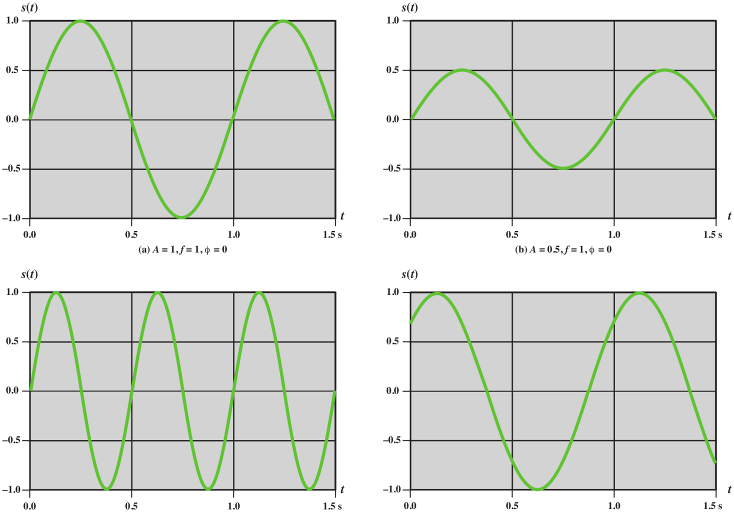
  **Phase, $\phi$:** relative position signal has advanced (or shifted) to some origin (usually 0) [radians]

- Other parameters:

  **Period, $T$:** time for one repetition or cycle; $T = 1/f$

  **Wavelength, $\lambda$:** distance occupied by one cycle; $\lambda = c/f$ where $c$ is speed of light ($\approx 3\text{x}10^8\text{m/s}$)

# Sinusoid Signal




(a) $A = 1, f = 1, \phi = 0$

(b) $A = 0.5, f = 1, \phi = 0$

(c) $A = 1, f = 2, \phi = 0$

(d) $A = 1, f = 1, \phi = \pi/4$

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# Frequency Domain Concepts

- Communication signals are composed of many component sinusoid signals at different frequencies, e.g.

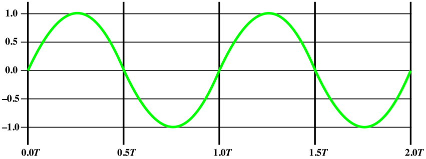
$$s(t) = (4/\pi) \times [\sin(200\pi t) + (1/3)\sin(600\pi t)]$$

- Or, if $f = 100Hz$:

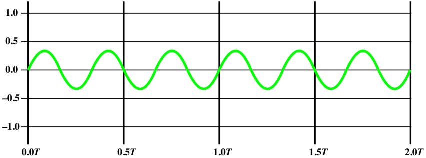
$$s(t) = (4/\pi) \times [\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$$

- When all frequency components of signal are integer multiple of one frequency, that one is called fundamental frequency; the others are harmonic frequencies
- Period of resulting signal is equal to period of fundamental frequency component
- By adding together sine waves with different amplitudes, frequencies and phases, any desired communications signal can be constructed

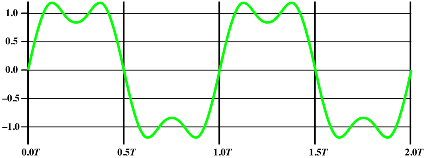
# Addition of Frequency Components




(a) sin (2πft)



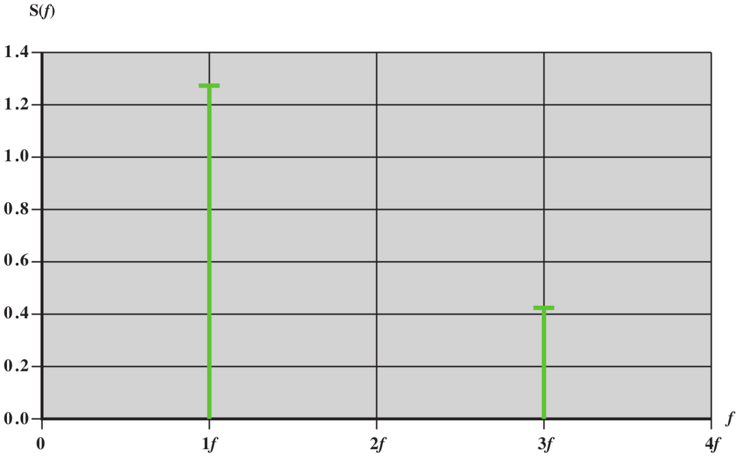

(b) (1/3) sin (2π(3f)t)




(c) (4/π) [sin (2πft) + (1/3) sin (2π(3f)t)]

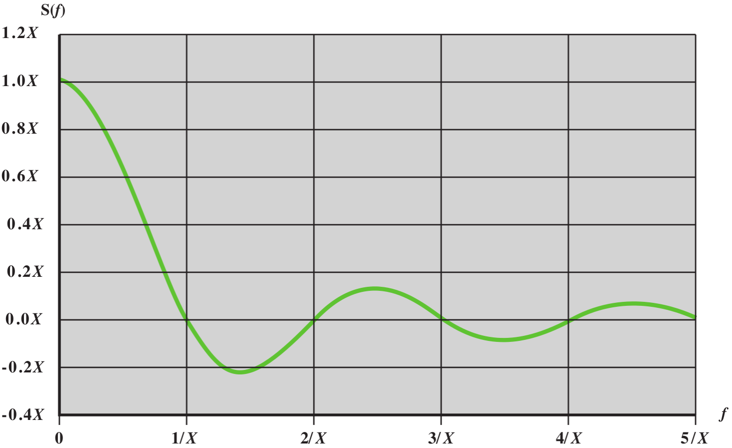
# Frequency Domain Representations

Frequency domain function, $S(f)$, specifies peak amplitude of component frequencies of signal




(a) $s(t) = (4/\pi)\,[\sin(2\pi f t) + (1/3)\sin(2\pi(3f)t)]$

# Frequency Domain Representations

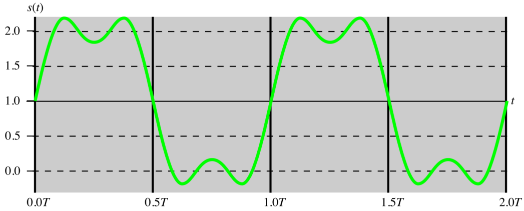



(b) s(t) = 1    − X/2 ≤ t ≤ X/2

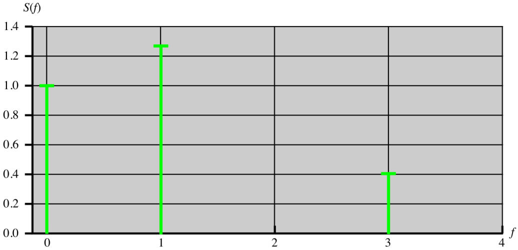
# Spectrum, Bandwidth and Data Rate

- Spectrum of a signal is range of frequencies it contains
- Absolute bandwidth is width of spectrum
- If signal contains component with zero frequency, signal has dc component
- Many signals have infinite absolute bandwidth, but most of the signal energy is contained in narrow band of frequencies; called Effective Bandwidth or just Bandwidth
- In practice, transmission system can only carry limited band of frequencies
- Bandwidth limit of system determines data rate

# Signal with dc Component

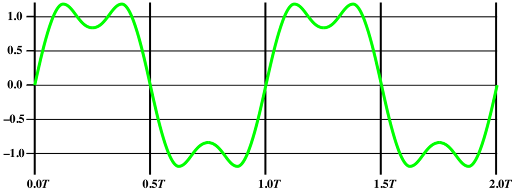



**(a) s(*t*) = 1 + (4/π) [sin (2π*ft*) + (1/3) sin (2π(3*f*)*t*)]**

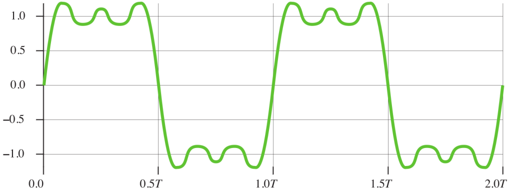



**(b) S(*f*)**

# Frequency Components of Square Wave: (a)

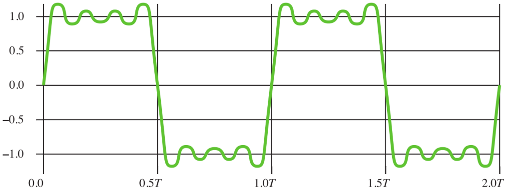



(c) (4/π) [sin (2πft) + (1/3) sin (2π(3f)t)]

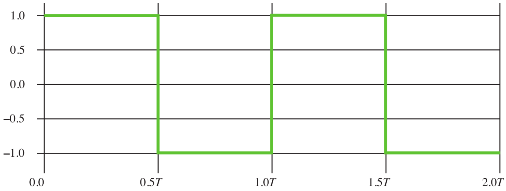



(a) (4/π) [sin (2πft) + (1/3) sin (2π(3f)t) + (1/5) sin (2π(5f)t)]

# Frequency Components of Square Wave: (b)




(b) $(4/\pi)\,[\sin(2\pi f t) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t) + (1/7)\sin(2\pi(7f)t)]$

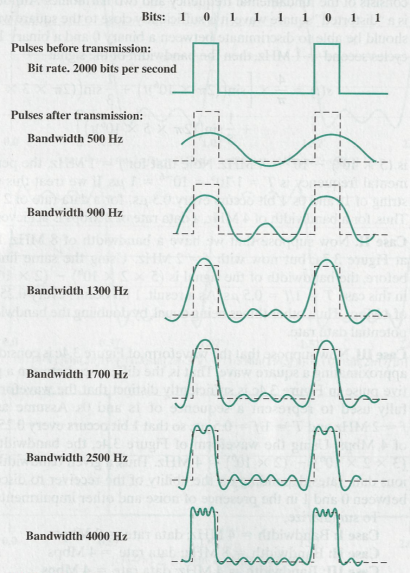



(c) $(4/\pi)\,\sum(1/k)\sin(2\pi(kf)t)$, for $k$ odd

# Example: Bandwidth and Data Rate

Digital transmission system can transmit signals with bandwidth of 4MHz. What is the maximum data rate? What if bandwidth increased to 8MHz?

# Effect of Bandwidth on a Digital Signal



# Tradeoffs

## Bandwidth

- Digital signal has infinite bandwidth; transmission systems impose limits on bandwidth of transmitted signals
- Bandwidth is a limited resource
- Greater the bandwidth, greater the cost

## Data Rate

- Digital data is approximated by signal of limited bandwidth
- Greater the bandwidth, greater the data rate

## Accuracy

- Receiver must be able to interpret received signal, even with transmission impairments

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# Analog and Digital ...

## Data

- Entities that convey meaning or information
- Analog data take continuous values over time, e.g. voice, video, sensor data
- Digital data take discrete values, e.g. text, integers

## Signals

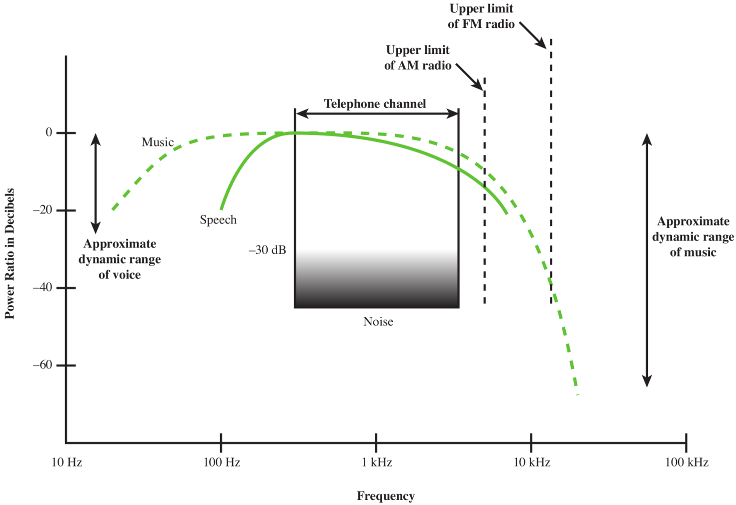
- Electric or electromagnetic representations of data

## Transmission

- Communication of data by propagating and processing signals

# Example of Analog Data: Audio

## Acoustic Spectrum of Speech and Music



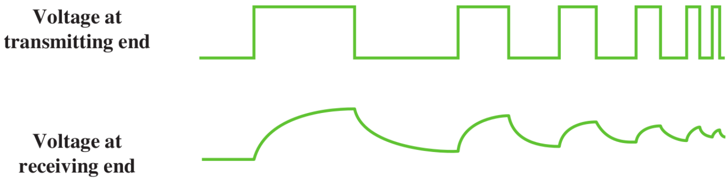
# Example of Digital Data: Text

First 3 bits

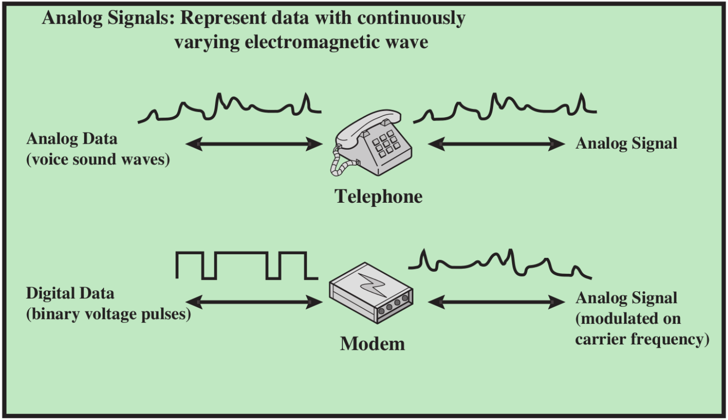
| Last 4 bits | 000 | 001 | 010 | 011 | 100 | 101 | 110 | 111 |
|---|---|---|---|---|---|---|---|---|
| 0000 | NUL | DLE | SP | 0 | @ | P | ` | p |
| 0001 | SOH | DC1 | ! | 1 | A | Q | a | q |
| 0010 | STX | DC2 | " | 2 | B | R | b | r |
| 0011 | ETX | DC3 | # | 3 | C | S | c | s |
| 0100 | EOT | DC4 | $ | 4 | D | T | d | t |
| 0101 | ENQ | NAK | % | 5 | E | U | e | u |
| 0110 | ACK | SYN | & | 6 | F | V | f | v |
| 0111 | BEL | ETB | ' | 7 | G | W | g | w |
| 1000 | BS | CAN | ( | 8 | H | X | h | x |
| 1001 | HT | EM | ) | 9 | I | Y | i | y |
| 1010 | LF | SUB | * | : | J | Z | j | z |
| 1011 | VT | ESC | + | ; | K | [ | k | { |
| 1100 | FF | FS | , | < | L | \ | l | \| |
| 1101 | CR | GS | – | = | M | ] | m | } |
| 1110 | SO | RS | . | > | N | ^ | n | ~ |
| 1111 | SI | US | / | ? | O | _ | o | DEL |

# Analog vs Digital Signals

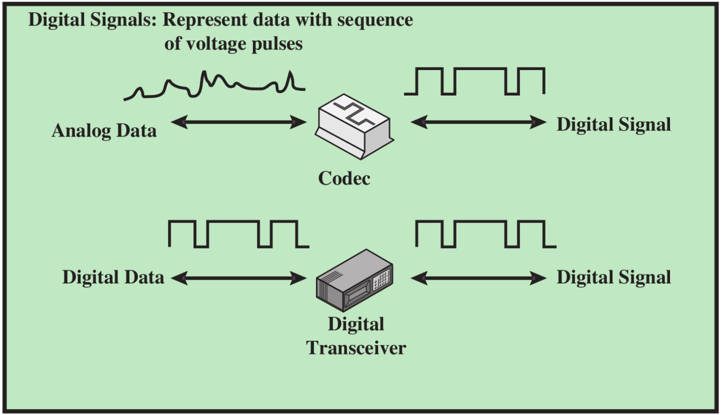
- Electric or electromagnetic representations of data
- Analog signal is continuously varying electromagnectic wave
- Digital signal is sequence of voltage pulses
- Digital signals generally cheaper and less susceptible to interference
- Digital signals suffer more from attenuation



# Analog Signaling of Analog and Digital Data



# Digital Signaling of Analog and Digital Data



# Ananlog/Digital Signals and Data

| | Analog Signal | Digital Signal |
|---|---|---|
| **Analog Data** | Two alternatives: (1) signal occupies the same spectrum as the analog data; (2) analog data are encoded to occupy a different portion of spectrum. | Analog data are encoded using a codec to produce a digital bit stream. |
| **Digital Data** | Digital data are encoded using a modem to produce analog signal. | Two alternatives: (1) signal consists of two voltage levels to represent the two binary values; (2) digital data are encoded to produce a digital signal with desired properties. |

# Analog vs Digital Transmission

- Analog transmission: analog signal is propagated through amplifiers
- Digital transmission: analog or digital signals are propagated through repeaters
- Digital transmission is preferred technology today: digital equipment, efficiently combine signals from different sources; security; repeaters can give more accurate data transmission

# Treatment of Signals in Analog/Digital Transmission

| | Analog Transmission | Digital Transmission |
|---|---|---|
| **Analog Signal** | Is propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data. | Assumes that the analog signal represents digital data. Signal is propagated through repeaters; at each repeater, digital data are recovered from inbound signal and used to generate a new analog outbound signal. |
| **Digital Signal** | Not used | Digital signal represents a stream of 1s and 0s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters; at each repeater, stream of 1s and 0s is recovered from inbound signal and used to generate a new digital outbound signal. |

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# Transmission Impairments

- Signal received may be different from signal transmitted causing:
  - Analog: degradation of signal quality
  - Digital: bit errors
- Most significant impairments:
  1. Attenuation and attenuation distortion
  2. Delay distortion
  3. Noise

# Attenuation

- Signal strength reduces as a function of distance
- Designing a transmission system:
  1. Received signal has sufficient strength to be interpreted by receiver electronics
  2. Received signal is significantly higher than received noise to avoid errors
- Attenuation distortion is a problem for analog signals:
  - Attenuation is different at different frequencies
  - Received signal has different strengths
  - Apply equalization to overcome

# Delay Distortion

- Component signals with different frequencies have different propagation delay through cable
- Some signal components representing a bit interfere with neighbour bits: intersymbol interference
- Apply equalization to overcome

# Noise

## Thermal Noise

- Due to thermal agitation of electrons
- Present in all transmission devices and media
- Function of temperature:

$$N = kTB$$

where k = Boltzmann's constant = $1.38 \times 20^{-23}$ J/K, B is bandwidth and T is temperature in kelvins

## Intermodulation Noise

- Caused when signals of different frequencies share the same medium

# Noise

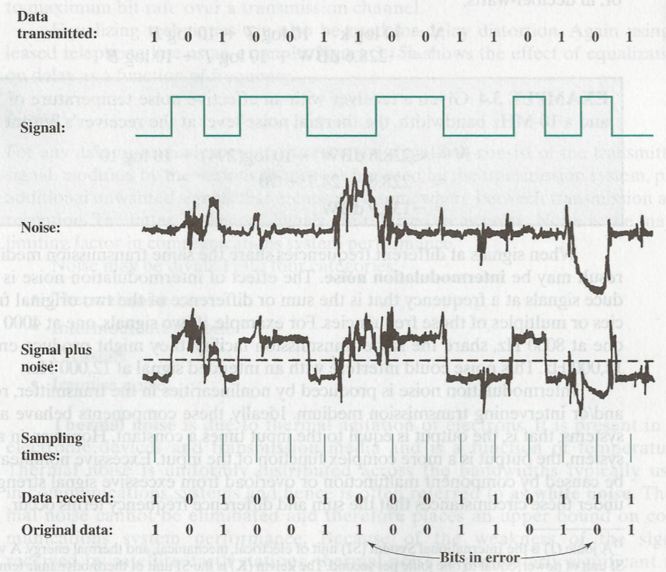
## Crosstalk

- Unwanted coupling of different signals

## Impulse Noise

- Short peak of noise, e.g. lightning, electrical disturbances, flaws in communications system

# Effect of Noise on a Digital Signal



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# Channel Capacity

- Channel capacity: maximum data rate at which data can be transmitted over a given communication channel
- Relate:
  - Data rate, $C$ [bits per second]
  - Bandwidth, $B$ [Hertz]
  - Noise
  - Error rate
- Two theoretical models:

  Nyquist Capacity: assumes noise-free environment

  Shannon Capacity: considers noise

# Nyquist Capacity

- Assumes channel that is noise free
- Given a bandwidth of $B$, the highest signal rate is $2B$
- Single signal element may carry more than 1 bit; signal with $M$ levels may carry $\log_2 M$ bits

$$C = 2B \log_2 M$$

- Tradeoffs:
  - Increase the bandwidth, increases the data rate
  - Increase the signal levels, increases the data rate
  - Increase the signal levels, harder for receiver to interpret the bits (practical limit to $M$)

# Example of Nyquist Capacity

A telephone system with modem allows bandwidth of 3100 Hz. What is the maximum data rate?

# Shannon Capacity

- With noise, some bits may be corrupted; higher data rate, more bits corrupted
- Increasing signal strength overcomes noise
- Signal-to-noise ratio:

$$SNR = \frac{signalpower}{noisepower}$$

- Shannon capacity:

$$C = B\log_2(1 + SNR)$$

- Tradeoffs:
  - Increase bandwidth or signal power, increases data rate
  - Increase of noise, reduces data rate
  - Increase bandwidth, allows more noise
  - Increase signal power, causes increased intermodulation noise

# Example of Shannon and Nyquist Capacity

A channel uses spectrum of between 3MHz and 4MHz, with $SNR_{dB} = 24dB$. How many signal levels are required to achieve Shannon capacity?