BEE3033 Data Communication and Networks

Lesson 2

Data Transmission

PowerPoint® Slides
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Analog & Digital Data Transmission

Common Terms

- Analog ➔ continuous
- Digital ➔ discrete
- Data ➔ Entities that convey meaning, or information.
- Signal ➔ electric or electromagnetic representations of data.
- Signaling ➔ physical propagation of the signal along a suitable medium.
- Transmission ➔ communication of data by the propagation and processing of signals.
- The term analog & digital are applied to data, signals, & transmission.

Analog & Digital Data

- Analog data ➔ take on continuous values in some interval. Example: voice, video, temperature, pressure, etc.
- Digital data ➔ take on discrete values. Example: text or character strings, images.
- Textual data cannot be easily stored or transmitted by data processing and communications systems. Thus, a number of codes have been devised to represent the characters with a sequence of bits.
- Today, the most commonly used text code is International Reference Alphabet (IRA). Each character is represented by a unique 7-bit pattern, thus 128 different characters can be represented.

Digital Data - Example

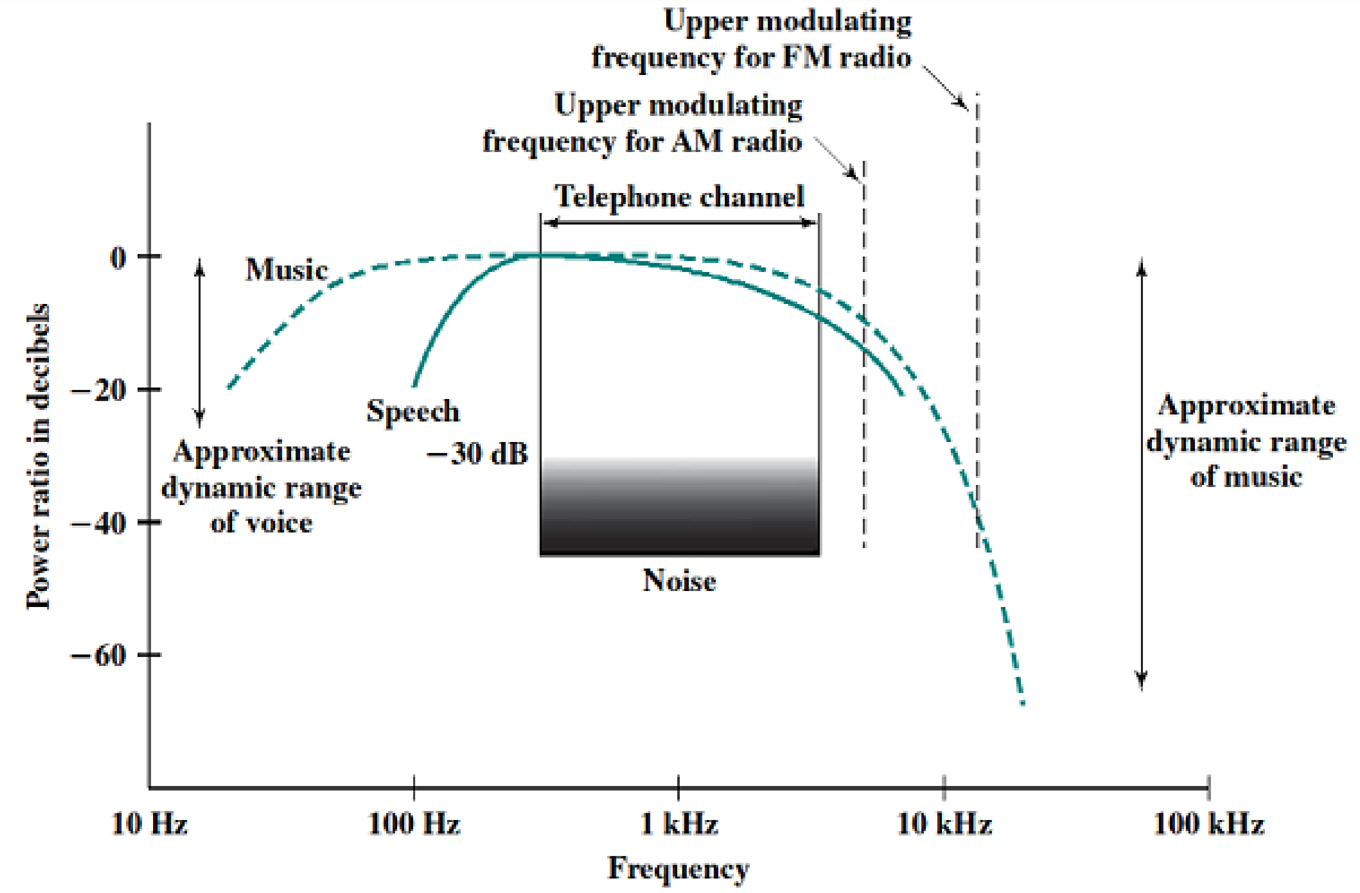
International Reference Alphabet (IRA)

Table 7.1 The International Reference Alphabet (IRA)

bit position											
			b_7	0	0	0	0	1	1	1	1
			b_6	0	0	1	1	0	0	1	1
			b_5	0	1	0	1	0	1	0	1
b_4	b_3	b_2	b_1								
0	0	0	0	NUL	DLE	SP	0	@	P	`	p
0	0	0	1	SOH	DC1	!	1	A	Q	a	q
0	0	1	0	STX	DC2	"	2	B	R	b	r
0	0	1	1	ETX	DC3	#	3	C	S	c	s
0	1	0	0	EOT	DC4	$	4	D	T	d	t
0	1	0	1	ENQ	NAK	%	5	E	U	e	u
0	1	1	0	ACK	SYN	&	6	F	V	f	v
0	1	1	1	BEL	ETB	'	7	G	W	g	w
1	0	0	0	BS	CAN	(	8	H	X	h	x
1	0	0	1	HT	EM	)	9	I	Y	i	y
1	0	1	0	LF	SUB	*	:	J	Z	j	z
1	0	1	1	VT	ESC	+	;	K	[	k	{
1	1	0	0	FF	FS	,	<	L	\	l	|
1	1	0	1	CR	GS	-	=	M	]	m	}
1	1	1	0	SO	RS	.	>	N	^	n	~
1	1	1	1	SI	US	/	?	O	_	o	DEL

- In the table, the bits of each character are labeled from b_7 (Most significant bit) to b_1 (Least significant bit)
- Example: The character "K" is $b_7b_6b_5b_4b_3b_2b_1 = 1001011$
- Characters are two types:printable and control.
- Printable characters are the alphabetic, numeric and special character that can be printed on paper or displayed on a screen.
- Control characters control some operation in the computer.

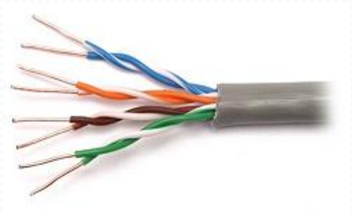
Analog Data - Example



Acoustic Spectrum of Speech and Music.

Analog & Digital Signals

- Data are propagated from one point to another by means of electromagnetic signals.
- Analog signal ➔ a continuously varying electromagnetic wave that may be propagated over a variety of media, depending on spectrum.
- Examples of media:
  - Wire media: twisted pair, coaxial cable, fiber optic cable.
  - Unguided media: space propagation.



twisted-pair

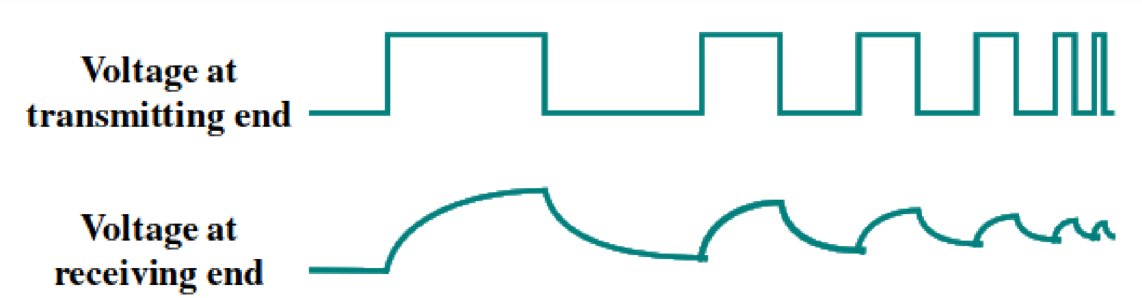
coaxial

fiber optic

Analog & Digital Signals

- Digital signal ➔ a sequence of voltage pulses that may be transmitted over a wire medium. Example, a constant positive voltage level may represent binary 0, and a constant negative voltage level may represent binary 1.
- Advantage of digital signaling:
  - cheaper than analog signaling
  - less susceptible to noise interference.
- Disadvantage of digital signaling:
  - Suffer more attenuation than analog signals

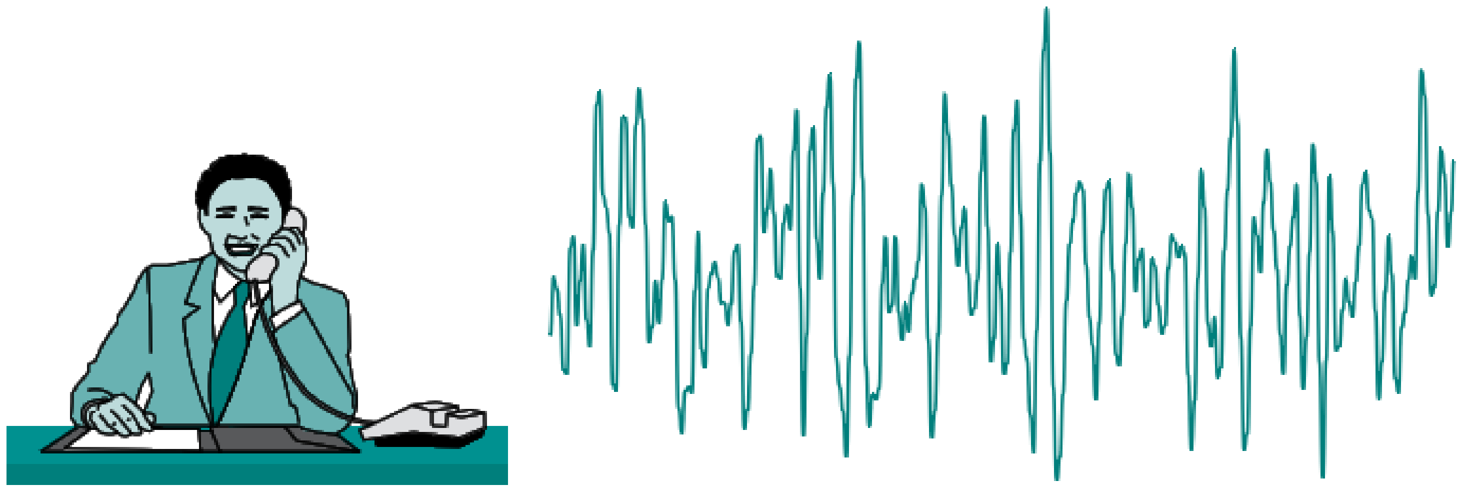
Digital Signals - Attenuation



Attenuation of digital signals.

- The above figure shows a sequence of voltage pulses, generated by a source using 2 voltage levels.
- Because of the attenuation, or reduction, of signal strength, the pulses become rounded and smaller.
- This attenuation can lead to the loss of information contained in the propagated signal.

Converstion to Analog Signals



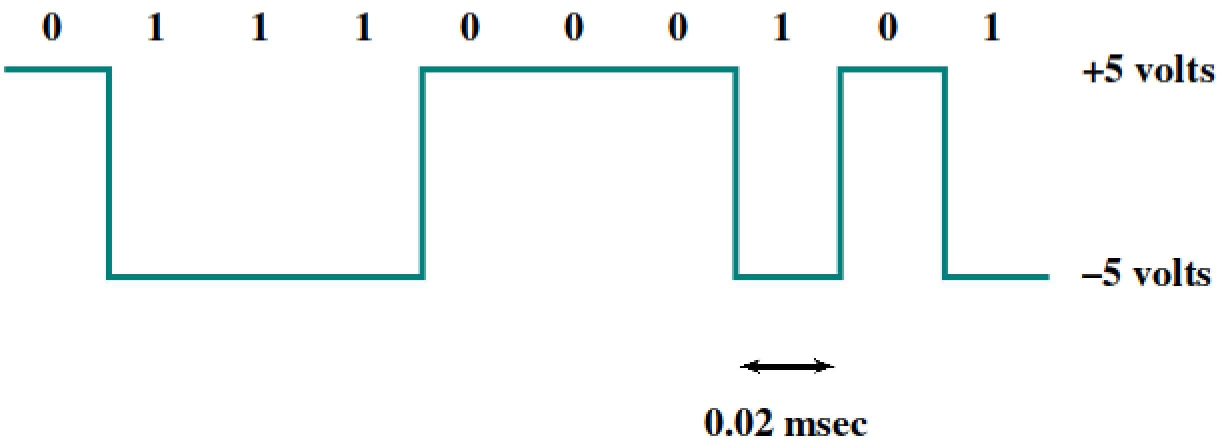
In this graph of a typical analog voice signal, the variations in amplitude and frequency convey the gradations of loudness and pitch in speech or music. Similar signals are used to transmit television pictures, but at much higher frequencies.

Conversion of voice input to analog signal.

Conversion to Analog Signals

- For acoustic data (voice), the data can be represented directly by an electromagnetic signal occupiyng the same spectrum.
- The spectrum of speech is approximately 100 Hz to 7 kHz. Yet a much narrower bandwidth will produce acceptable voice reproduction. The standard specturm for a voice channel is 300 to 3400 Hz. This is adequate for speech transmission, minimizes required transmission capacity, and cheaper telephone set.

Conversion to Digital Signals

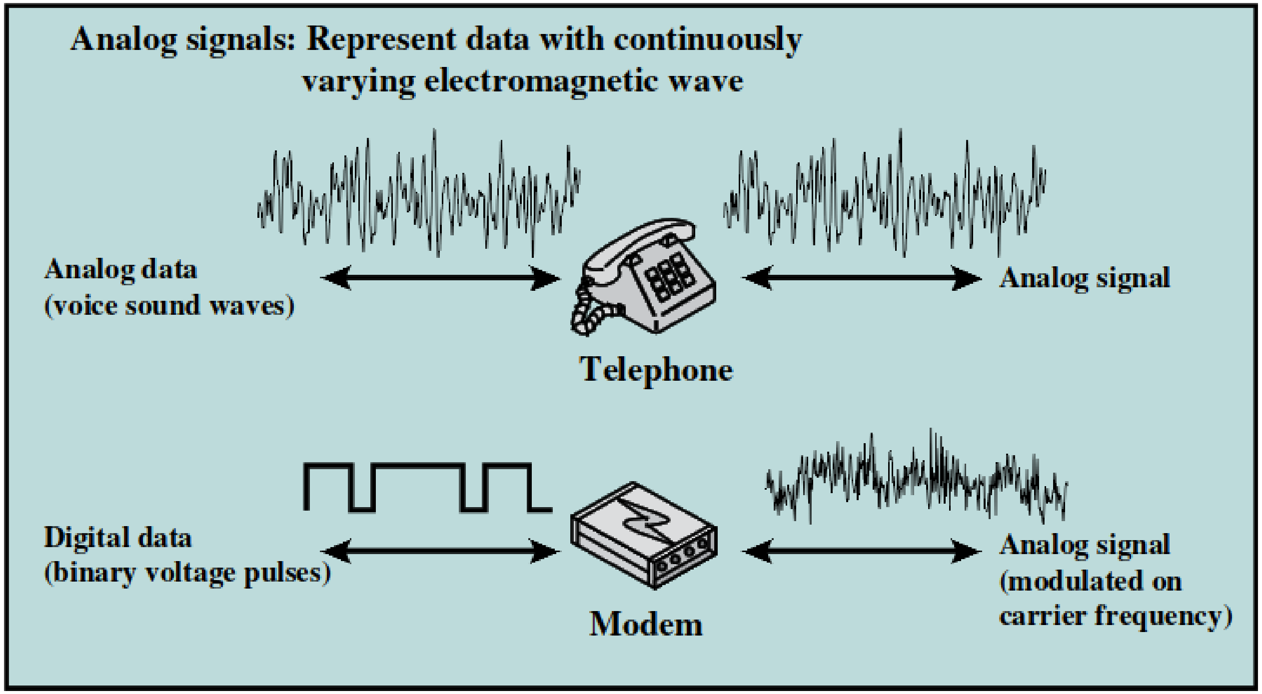


User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by –5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).

Conversion of PC input to digital signal.

Analog Signaling

- Digital data can also be represented by analog signal, using a modem (modulator/demodulator).



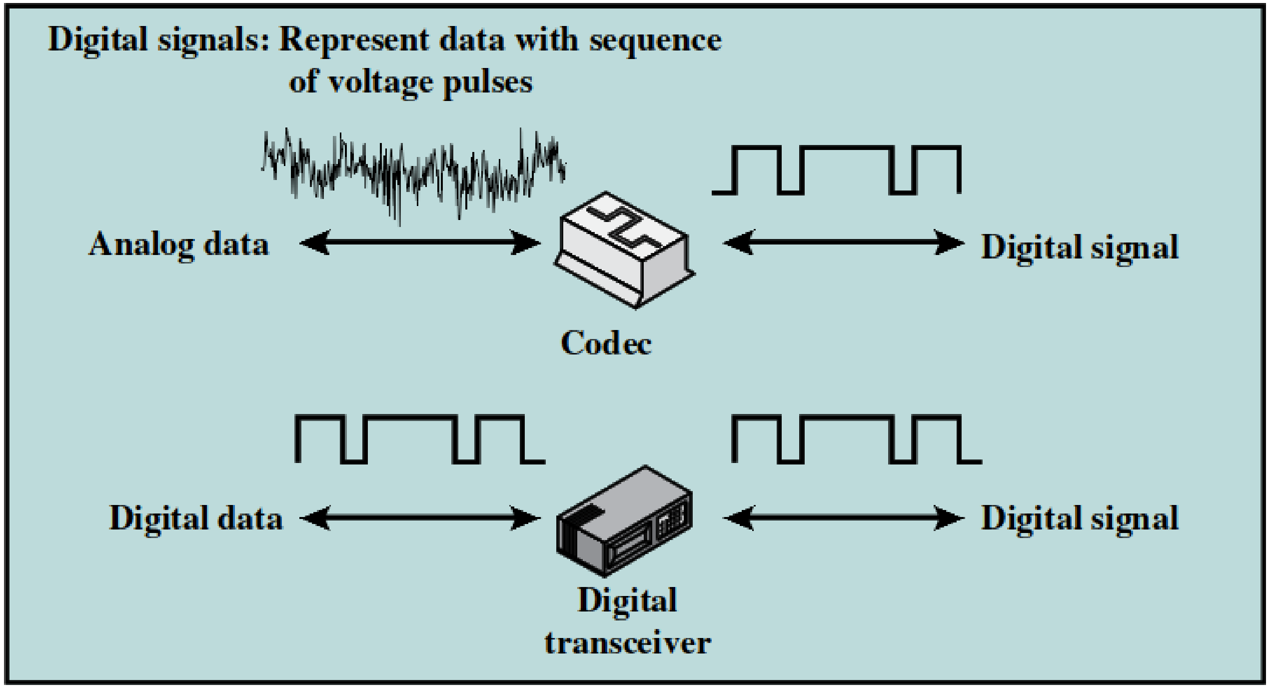
Analog signaling of digital data.

Analog Signaling

- Modem converts a series of binary (2-valued) voltage pulses into an analog signal by encoding the digital data onto a carrier frequency.
- The resulting signal occupies a certain spectrum of frequency centered about the carrier and may be propagated across a medium suitable for that carrier.
- The most common modems represent digital data in the voice spectrum and hence allow those data to be propagated over ordinary voice-grade telephone lines.
- At the other end, another modem demodulates the signal to recover the original data.

Digital Signaling

- Analog data can also be represented by digital signal, using codec (coder-decoder).



Digital signaling of analog data.

Digital Signaling

- Codec takes an analog signal that directly represents the voice data and approximates that signal by a bit stream.
- At the receiving end, the bit stream is used to reconstruct the analog data.

Analog vs Digital Signaling

	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 Transmission

- Analog transmission transmit anolog signals without regard to their content; the signals may represent analog data (i.e. voice) or digital data (i.e. binary data that pass through a modem).
- The analog signal will become weaker (attenuate) after a certain distance.
- To achieve longer distances, the analog transmission system includes amplifiers that boost the energy in the signal. Unfortunately, the amplifier also boosts the noise components.

Digital Transmission

- Digital transmission assumes a binary content to the signal.
- A digital signal can be transmitted only to a limited distance before attenuation, noise, and their impairments endanger the integrity of the data.
- To achieve greater distances, repeaters are used. A repeater receives the digital signal, recovers the pattern of 1 s and 0 s, and retransmits a new signal. Thus the attenuation is overcome.
- *Which method is better? Analog or digital transmission?*

Digital Transmission

- Digital trassmission is better because:
  - Digital technology – large-scale integration (LSI) & very-large-scale integration (VLSI) technology has caused a continuing drop in the cost and size of digital circuitry.
  - Data integrity – With the use of repeaters rather than amplifiers, the effects of noise & other signal impairments are not cumulative.
  - Capacity utilization – a high degree of multiplexing to achieve high capacity can be more easily and cheaply achieved with digital technique.
  - Security & privacy – encryption can be readily applied to digital data & to analog data that have been digitized.
  - Integration – By treating both analog & digital data digitally, all signals have the same form & can be treated similarly.

Transmission Difficulties

- The reception of digital data involves sampling the incoming signal once per bit time to determine the binary value.
- One of the difficulties encountered is that various transmission impairments will corrupt the signal.
- This problem is compounded by a timing difficulty: In order for the receiver to sample the incoming bits properly, it must know the arrival time & duration of each bit that it receives.

Transmission Difficulties

- Example: If data are to be transmitted at 1 Mbps, then one bit will be transmitted every $1/10^6$ = 1 μs, as measured by the sender's clock. The sampling occur once every 1 μs.
- The receiver will attempt to sample the medium at the center of each bit time. (0.5 μs in this example)
- If the receiver times its samples based on its own clock, then there will be a problem if the transmitter's and receiver's clocks are not precisely aligned. If there is a drift of 1%, then the first sampling will be 0.01 of a bit time (0.01 μs) away from the center of the bit. After 50 or more samples, the receiver may be in error because it is sampling in the wrong bit time (50 x 0.01 μs = 0.5 μs)
- 2 approaches: asynchronous & synchronous transmission.

Asynchronous Transmission

- This strategy avoid the timing problem by not sending long, uninterrupted streams of bits. Instead, data are transmitted one character at a time, where each character is 5 to 8 bits in length.
- Timing or synchronization must only be maintained within each character; the receiver has the opportunity to resynchronize at the beginning of each new character.

Synchronous Transmission

- A block of bits is transmitted in a steady stream without start and stop codes. The block may be many bits in length.
- To prevent timing drift between transmitter & receiver, their clocks must be synchronized.
- One side (transmitter or receiver) pulses the line regularly with one short pulse per bit time. The other side uses these regular pulses as a clock. This technique works well over short distances, but over longer distances the clock pulses are subject to the same impairments as the data signal, and timing errors can occur.
- One technique is to embed the clocking infomation in the data signal.

Synchronous Transmission

- With synchronous transmission, there is another level of synchronization required to allow the receiver to determine the beginning and end of a block of data.
- To achieve this, each block begins with a preamble bit pattern and generally ends with a postamble bit pattern.
- In addition, other bits are added to the block that conveys control information used in the data link control procedures.
- The data plus preamble, postamble, and control information are called a frame.

Transmission Impairments

- The most significant impairments are:
  - Attenuation – the strength of a signal falls off with distance over any transmission medium.
  - Delay distortion – occurs in transmission cables (such as twisted pair, coaxial cable, optical fiber); it doesn’t occur when signals are transmitted through air by antennas.
  - Noise:
    - Thermal noise – thermal agitation of electrons.
    - Intermodulation noise – when signals at different frequencies share the same transmission medium.
    - Crosstalk – unwanted coupling between signal paths.
    - Impulse noise – irregular pulses or noise spikes of short duration & relatively high amplitude.

Channel Capacity

Channel Capacity

- Channel capacity ➔ the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions.
- There are 4 concepts that relate to each other:
  - Data rate ➔ the rate, in bits per second (bps), at which data can be communicated.
  - Bandwidth ➔ bandwidth of the transmitted signal, as constrained by the transmitter & transmission medium. In cycles per second, or hertz.
  - Noise
  - Error rate ➔ the rate at which errors occur.

Channel Capacity

- Communications facilities are expensive, the greater the bandwidth of a facility, the greater the cost. All transmission channels have limited bandwidth.
- For digital data, we want to get as high a data rate as possible at a particular limit of error rate for a given bandwidth.
- The main constraint on achieving this efficiency is noise.

Nyquist Bandwidth

- Let's consider a channel that is noise free. Then, the limitation on data rate is simply the bandwidth of the signal.
- Nyquist ➔ if the rate of signal transmission is *2B*, then a signal with frequencies no greater than *B* is sufficient to carry the signal rate.
- The converse is also true: Given a bandwidth of B, the highest signal rate that can be carried is 2B.
- For multilevel signaling, Nyquist capacity:

$$\boxed{C = 2B\log_2 M}$$

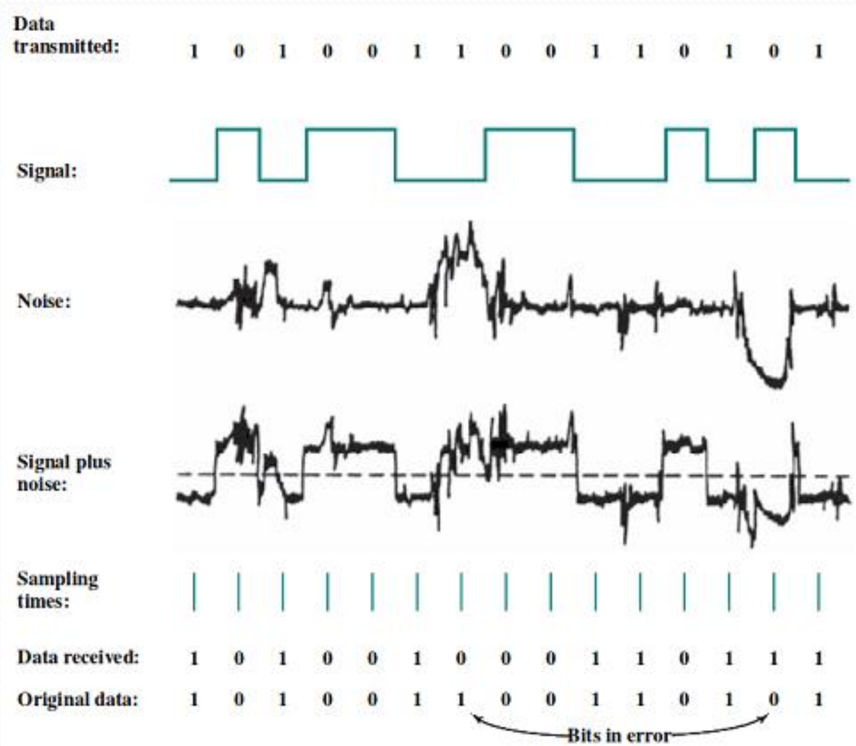
M = number of discrete signal or voltage levels

<u>Example</u>: Consider a voice channel, that use modem, to transmit digital data. Assume a bandwidth of 3100 Hz, M = 8, what is the Nyquist capacity?

Effect of Noise

- The presence of noise can corrupt 1 or more bits. If the data rate is increased, then the bits become "shorter" so that more bits are affected by a given pattern of noise.

- If the data rate is increased, then more bits will occur during the interval of a noise spike, and hence more errors will occur.



Effect of noise on a digital signal.

Signal-to-Noise Ratio (SNR)

- Signal-to-noise ratio (SNR or S/N) ➔ ratio of the power in a signal to the power contained in the noise that is present at a particular point in the transmission.

$$\boxed{\mathrm{SNR}_{dB} = 10\log_{10}\frac{\text{signal power}}{\text{noise power}}} \qquad \text{(decibels)}$$

- It expresses the amount, in decibels, that the intended signal exceeds the noise level. A high SNR means a high-quality signal & a low number of required intermediate repeaters.
- This ratio is measured at a receiver, because here is where an attempt is made to process the signal and recover the data.

Shannon Capacity

- Maximum channel capacity (Shannon capacity):

$$\boxed{C = B\log_2(1+\mathrm{SNR})} \qquad \text{(bits per second)} \qquad \text{Eq.1}$$

  C is the capacity of the channel, in bits per second

  B is the bandwidth of the channel, in hertz.

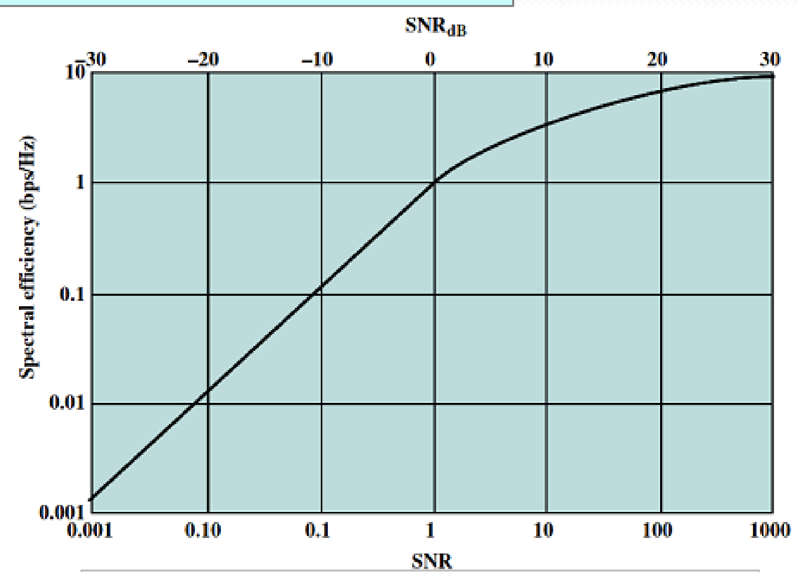
- Shannon formula represents the theoretical maximum. But in practice, only much lower rates are achieved. It's because there are impulse noise, attenuation and delay distortion.
- The above Shannon capacity formula is referred to as the error-free capacity.

Spectral Efficiency

- Spectral efficiency == bandwidth efficiency ➔ the number of bits per second of data that can be supported by each hertz of bandwidth in a digital transmission.

$$\boxed{C = B\log_2(1+\mathrm{SNR})} \Rightarrow \boxed{C/B = \log_2(1+\mathrm{SNR})} \quad \text{(bps/Hz)}$$

- At SNR = 1, C/B = 1
- For SNR < 1, signal power is less than noise power, the plot is linear.
- For SNR > 1, the plot flattens but continue to increase with increasing SNR.



Spectral efficiency versus SNR.

Spectral Efficiency

- From previous figure, below 0 dB SNR, noise is the dominant factor in the capacity of a channel. Though communication is possible but at a relatively low data rate.
- In the region of at least 6 dB above 0 dB SNR, noise is no longer the limiting factor, thus achieving a high-channel capacity.
- For a given level of noise, the data rate could be increased by increasing either signal strength or bandwidth. However,
    - as the signal strength increases, it also increases the intermodulation noise.
    - The wider the bandwidth, the more noise is admitted to the system. As *B* increases, SNR decreases.

Example

Suppose the spectrum of a channel is between 3 MHz and 4 MHz. The SNR_{dB} = 24 dB. Determine:

(a) Shannon channel capacity

(b) Spectral efficiency

(c) Signaling level