Code Division Multiplexing:- It is widely used in so-called 2G & 3G wireless communication.

- It is a combination of analog-to-digital conversion and spread spectrum technology.
- It is also known as CDMA (Code Division Multiple Access)
- CDMA allows each station to transmit over the entire frequency all the time.
- In CDM, each station is assigned a code called chip sequence. Transmission occurs in the foll way:-
- If a station needs to transmit a '1' bit, then it sends its chip sequence.
- If a station needs to transmit a '0' bit, then it sends negation of its chip sequence.
- Consider a station A and its chip sequence,

$$A = (-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1)$$

If 'A' needs to transmit bit '1', then it sends

$$(-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1)$$

If 'A' needs to transmit bit '0', then it transmits

$$\text{negation} \Rightarrow (+1\ +1\ +1\ -1\ -1\ +1\ -1\ -1)$$

- All chip sequences are pairwise orthogonal means that the normalized inner product of any two distinct chip sequences, S and T is '0'.

- chip sequences has the following properties:

$S \cdot T = 0$ $\quad S \cdot \bar{T} = 0$ $\quad S \cdot \bar{S} = -1$

$S \cdot S = 1$ $\quad \bar{S} \cdot T = 0$

- Consider 4 stations A, B, C, D & their chip sequences:

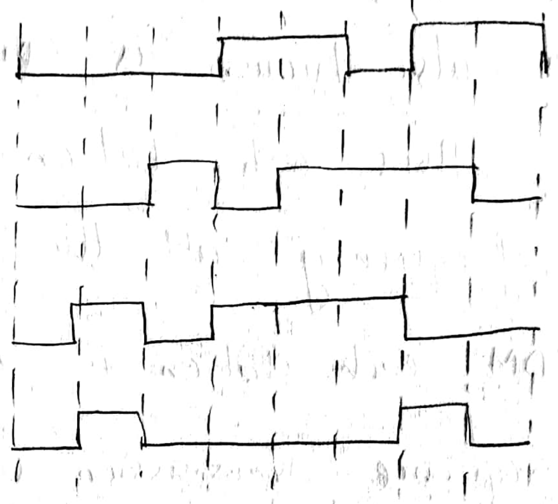
$A = (-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1)$

$B = (-1\ -1\ +1\ -1\ +1\ +1\ +1\ -1)$

$C = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$

$D = (-1\ +1\ -1\ -1\ -1\ -1\ +1\ -1)$

chip sequences



Signals the sequences represent

- The foll are the six examples of one or more stations transmitting 1 bit at the same time.

$S_1 = C$ [station 'c' transmits a '1' bit]

$S_2 = B + C$ [both B & C transmit '1' bit]

$S_3 = A + \bar{B}$ [A transmits '1' & B transmits '0']

$S_4 = A + \bar{B} + C$ [A transmits '1', B transmits '0', C transmits '1']

$S_5 = A + B + C + D$ [A transmits '1', B transmits '1', C transmits '1', D transmits '1']

$S_6 = A + B + \bar{C} + D$ [A transmits '1', B transmits '1', C transmits '0', D transmits '1'].

- Their chip sequences are as follows:-

$S_1 = C = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$

$S_2 = B + C = (-1\ -1\ +1\ -1\ +1\ +1\ +1\ -1) + (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$

$= (-2\ 0\ 0\ 0\ +2\ +2\ 0\ -2)$

$S_3 = A + \overline{B} = (-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1) + (+1\ +1\ -1\ +1\ -1\ -1\ -1\ +1)$

$= (0\ 0\ -2\ +2\ 0\ -2\ 0\ +2)$

$S_4 = A + \overline{B} + C = (-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1) + (+1\ +1\ -1\ +1\ -1\ -1\ -1\ +1)$
$+ (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$

$= (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1)$

$S_5 = A + B + C + D = (-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1) + (-1\ -1\ +1\ -1\ +1\ +1\ +1\ -1) +$
$(-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1) + (-1\ +1\ -1\ -1\ -1\ -1\ +1\ -1)$

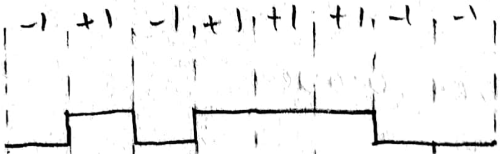
$= (-4\ 0\ -2\ 0\ +2\ 0\ +2\ -2)$

$S_6 = A + B + \overline{C} + D = (-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1) + (-1\ -1\ +1\ -1\ +1\ +1\ +1\ -1) +$
$(+1\ -1\ +1\ -1\ -1\ -1\ +1\ +1) + (-1\ +1\ -1\ -1\ -1\ -1\ +1\ -1)$

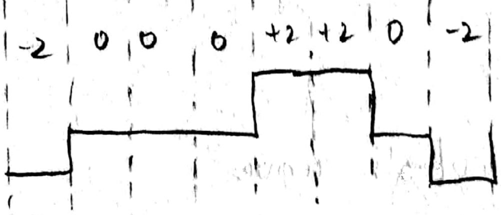
$= (-2\ -2\ 0\ -2\ 0\ -2\ +4\ 0)$

- signal representation of above examples is as follows:-

$S_1 = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$



$S_2 = (-2\ 0\ 0\ 0\ +2\ +2\ 0\ -2)$

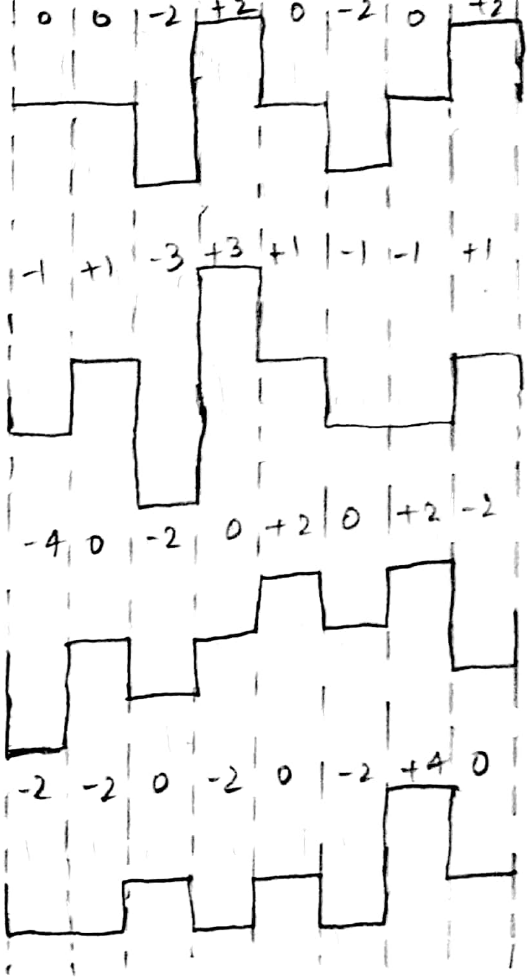


$S_3 = (0\ 0\ -2\ +2\ 0\ -2\ 0\ +2)$

$S_4 = (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1)$

$S_5 = (-4\ 0\ -2\ 0\ +2\ 0\ +2\ -2)$

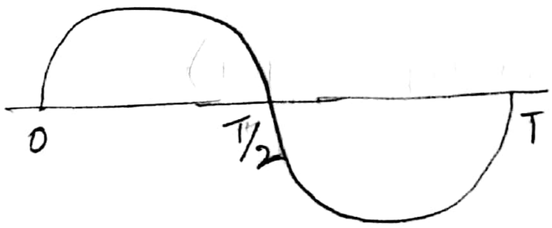
$S_6 = (-2\ -2\ 0\ -2\ 0\ -2\ +4\ 0)$



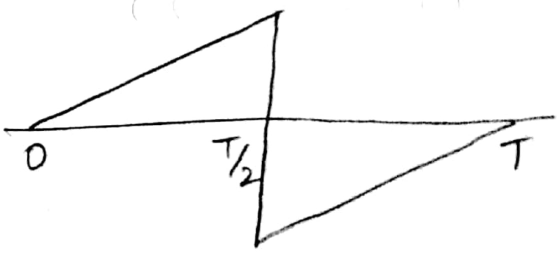
<u>Fourier Analysis</u>, <u>Bandwidth Limited Signals</u>, <u>Max Data rate of channel</u>

- <u>periodic waveform</u>: It is one which repeats the exact same shape again & again. It doesn't change its shape, stay the same for the waveform's whole duration.
- There are five periodic waveforms:- They are :-

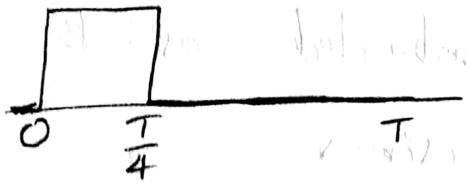
ⓐ Sine wave



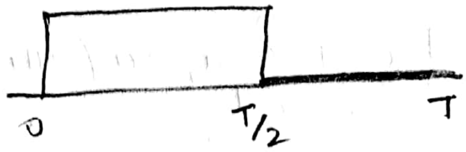
ⓑ Sawtooth wave



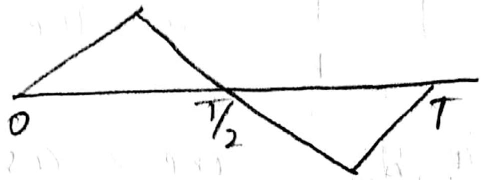
(c) pulse wave



(d) Square wave



(e) Triangle wave



- Information can be transmitted on wires by varying some physical property such as voltage or current.
- We represent this voltage or current as a single-valued function of time, $f(t)$.
- Then we can model the behaviour of the signal & analyze it mathematically
- This analysis is done in the following concepts:-

  Fourier Analysis
  Bandwidth Limited Signals
  Maximum Data Rate of a chanel.

Fourier Analysis:-

- In early 19th century, the French mathematician Jean-Baptiste Fourier proved that any reasonably behaved periodic function, $g(t)$ with period T, can be constructed as the sum of a number of sines and cosines.

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t) \quad (1)$$

$f = \frac{1}{T}$ is the fundamental frequency

a_n, b_n = sine & cosine amplitudes

c = constant

Such a decomposition is called a Fourier series

- The a_n amplitudes can be computed for any given $g(t)$ by multiplying both sides of eq (1) by $\sin(2\pi k f t)$ & then integrated from 0 to T.
- Similarly by multiplying (1) by $\cos(2\pi k f t)$ & integrating from 0 to T we can derive b_n.
- By just integrating both sides of the equation, we can find c,

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

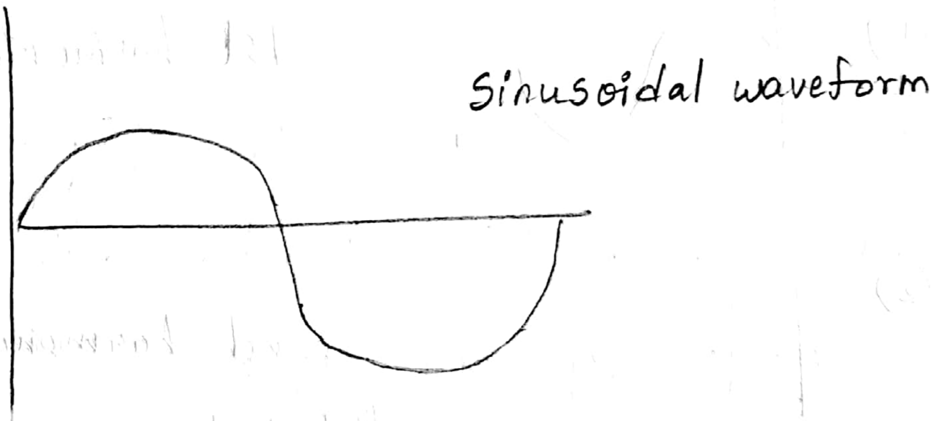
$$b_n = \frac{2}{T}\int_0^T g(t) \cos(2\pi n f t)\, dt$$

$$c = \frac{2}{T}\int_0^T g(t)\, dt.$$

Bandwidth Limited Signals :

Fundamental frequency :

- A fundamental waveform (or first harmonic) is the Sinusoidal waveform that has the supply frequency
- The fundamental is the lowest or base frequency 'f' on which the waveform is built.
- Consider a basic 1st harmonic AC waveform.



- Harmonics :- They are voltages or currents that operate at a frequency that is an integer multiple of fundamental frequency.

  Ex :- If fundamental frequency = 50 Hz

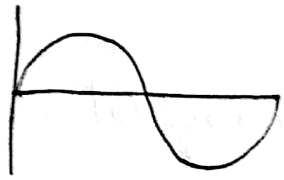
  1st harmonic frequency = 50 Hz
  2nd harmonic frequency = 100 Hz
  3rd harmonic frequency = 150 Hz ..... etc.

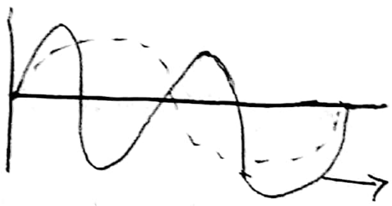
- So, if the fundamental frequency = f

1st harmonic frequency = f
2nd harmonic frequency = 2f
3rd harmonic frequency = 3f . . . . etc.

- Harmonics are unwanted higher frequencies which superimposed on fundamental waveform creating a distorted wave pattern.

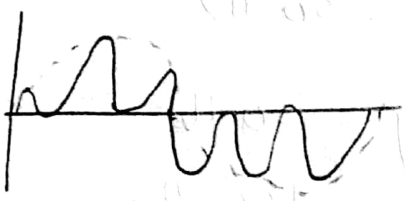
- <u>Waveforms due to Harmonics</u> :

(1)  1st harmonic : f

(2)  2nd harmonic : 2f

→ distorted wave due to harmonics

(3)  3rd harmonic : 3f

(4)  4th harmonic : 4f

- <u>Bandwidth</u> : The range of frequencies that are used for transmitting a signal without being attenuated is called the bandwidth.

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$$B = f_{max} - f_{mini}$$

Ex :- If max frequency $= 1000$,
min frequency $= 100$

$$B = 1000 - 100$$

$$\boxed{B = 900}$$

- <u>baseband</u> <u>signals</u>: Signals that run from 0 upto a maximum frequency are called baseband signals.

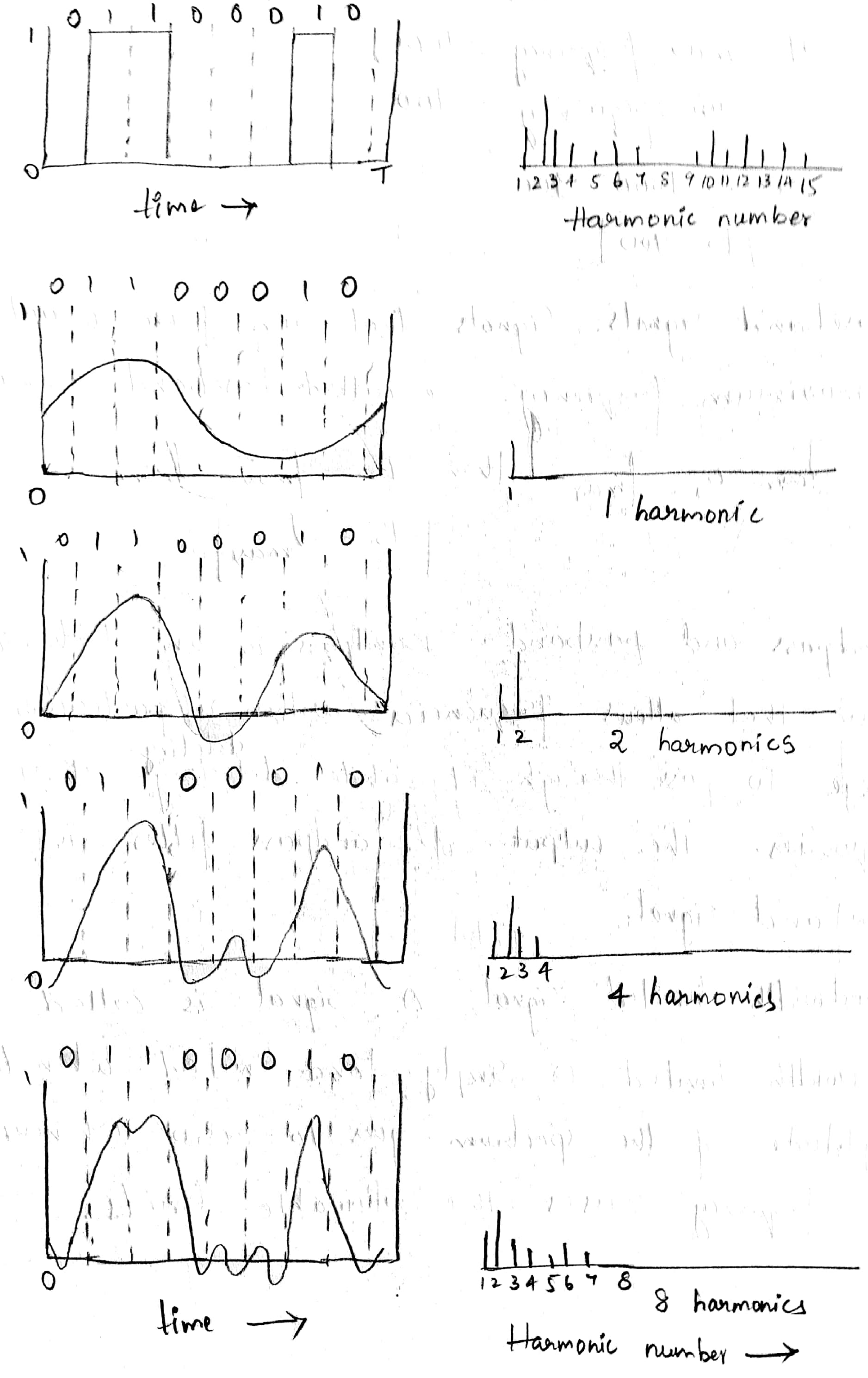
$f_{min} = 0$, f_{max} then $B = f_{max} - f_{mini}$

$$\boxed{B = f_{max}}$$

- <u>Bandpass</u> <u>and</u> <u>passband</u>: Bandpass is an electronic filter that allows frequencies within a particular range to pass through it while ~~detecting~~ deleting other frequencies. The output of bandpass filter is <u>passband signal</u>.

- <u>Bandwidth</u> <u>-limited</u> <u>signal</u>: A signal is called bandwidth - limited or simply band-limited when the amplitude of the spectrum goes to zero whenever its frequency crosses the allowable limits.

Ex :- Data is 01100010



Maximum Data Rate of a channel :

- Limiting the bandwidth limits the data rate.

Nyquist theorem :- The maximum data rate of a channel can be calculated for an error-free/noiseless channel by using the foll equation.

$$\boxed{\text{max data rate} = 2B\log_2 V \text{ bits/sec}}$$

B = Bandwidth

V = discrete signal levels.

This equation is applicable for error-free channel.

Shannon's theorem : For a noisy channel, the maximum data rate of a channel is calculated by using the foll equation.

$$\boxed{\text{max data rate} = B\log_2(1 + S/N)}$$

The amount of noise present is measured by the ratio of signal power to noise power. called SNR (Signal-to-Noise Ratio). (S/N)