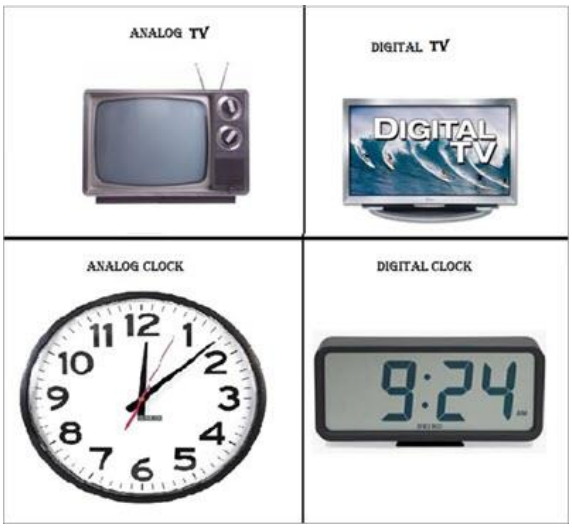
# Lecture 4

## Signal Types: Analog Vs Digital

In the current world, information is the key to survival and not just success. Signals are the means through which information is transmitted from one point to another. So, it does not confine the jobs to anyone's professional area. Every industry segment requires data to be transmitted.

There is a job opportunity for signal engineers in manufacturing, electronics, technology, etc. Refer to the below image for the Analog vs Digital application example.




## Understanding Features of Digital Vs Analog Signals

Analog and digital signals are two types of signals which carry information from one point or apparatus to another point or apparatus.

**Let us understand the difference between analog and digital in detail:**

## Analog signal:

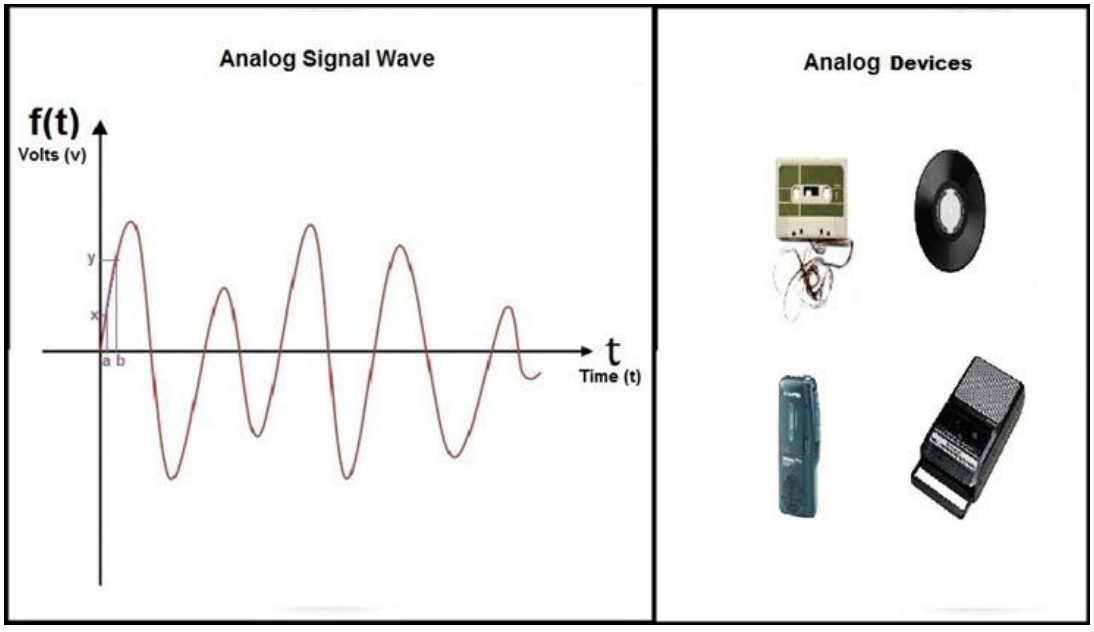
- It is a continuous signal and can have infinite values in a given time period.
- They can be quantified using amplitude or frequency across a time period.
- Analog signals become weaker as they traverse. The transmission quality deteriorates during transmission as the interferences produce a lot of noise.
- Some simple steps to reduce noise interference are to use short signal wires which are twisted. Electric machinery and other electric gadgets should be kept away from the wires. Using differential inputs can help in reducing noise common to the two wires.
- Analog signals can be amplified using amplifiers, but they intensify noise as well.
- All real-life signals are Analog.

- The colors we see, the sounds we make and hear, the heat we feel are all in the form of Analog signals. Temperature, sound, velocity, pressure is all analog in nature.
- Analog recording technique is used for storing analog signals. The record storing these audio signals can be played back later.
- An electronic technique like wire and tape recording are some examples. In this method, the signals are stored directly in the media as physical textures on a phonograph record or as fluctuations in the magnetic field strength of a magnetic record.

In the chart below, the **x-axis** is the timeline and the **Y-axis** is the voltage of the signal. Between the time interval between point a and point b in the x-axis, the voltage value is between the value at point x and point y in the Y-axis. The number of voltage values between point x and point Y is infinite i.e., voltage value if taken at every small interval between the time a and time b is infinite.
This is the reason that Analog signals are said to capture infinite values in a given time period.

In the Analog clock image above, the time is 12 hrs. 8 min and 20 secs. But we can also tell the time if it was say less than 20 secs and more than 15 secs when the second's hand has not yet reached the 20 sec's line. So, this clock actually shows the time in nano and micro-nano secs as well. But since it is not calibrated, we are not able to read it.

## Analog Signal Wave:



## Digital signals:

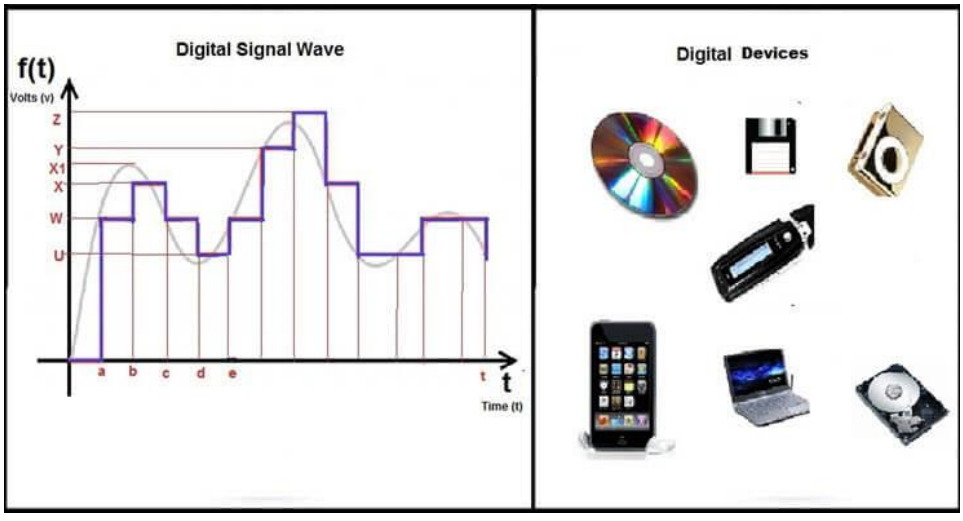
- Carry the data, but these signals are not continuous but discreet.
- In digital waves, the signals are defined for the discreet value of time. All discreet time signals are a subset of analog signals.
- When looked at from far, a digital wave will also look smooth and continuous, but at close quarters the tiny discreet steps can be seen.
- For any small range of a digital wave, from any two points, there may be infinite points but finite values only.
- So, digital signals include a limited variety of values that can be encoded in binary, i.e., 0 and1. They carry the data in binary form.
- Digital signals are used in communication mainly because of negligible impact on quality due to noise.
- Digital signals also become weaker as they traverse and can be amplified using digital regenerators. The regenerated digital waves can be of better quality, with no noise interference.

In the digital clock image above, the time is 9 hrs. 24 min. But this clock will not show time in seconds, as the data interval defined is a minute. So, the values in between i.e., seconds are not captured.

In the chart below the x-axis is the timeline and Y-axis is the voltage of the signal. The grey sine wave curve is the Analog graph captured and the Purple graph is the digital graph captured at discreet time intervals from a to t. Between the time interval between point a and point b in the x-axis the voltage value at a is ‘W’ and at b is ‘X1’ in the grey Analog wave.

But in the Y-axis there is no value marked for capturing at X1 in the digital graph. So, the value is normalized and brought to the nearest captured value X in the digital graph. Similarly, the actual intermediate values between point a and b are all ignored and are a straight line instead of a curve.

## Digital Signal Wave:



## Differences Between Analog and Digital Signal

Listed below the key difference between Digital and Analog Signal

| Key Characteristics | Analog Signal | Digital Signal |
|---|---|---|
| **Data Value** | Continuous values across time spanC | Limited to distinct set of values across disc intervals |
| **Wave Type** | Sine Wave | Square Wave |
| **Representation** |  |  |
| **Polarity** | Both negative and positive values | Only positive values |
| **Processing Offered** | Easy | Quite complex |
| **Accuracy** | More Accurate | Less Accurate |
| **Decoding** | Difficult to understand and decode | Easy to understand and decode |
| **Security** | Not Encrypted | Encrypted |
| **Bandwidth** | Low | High |
| **Parameters Associated** | Amplitude, frequency, phase, etc. | Bit rate, bit interval, etc. |
| **Transmission Quality** | Deterioration due to noise interference | Almost zero interference of noise resultin transmission quality |
| **Data Storage** | Data is stored in wave form | Data is stored in binary bit form |
| **Data Density** | More | Less |
| **Power Consumption** | More | Less |

| Key Characteristics | Analog Signal | Digital Signal |
|---|---|---|
| **Transmission Mode** | Wire or Wireless | Wire |
| **Impedance** | Low | High |
| **Transmission Rate** | Slow | Fast |
| **Hardware Implementation Adaptability** | Offers No flexibility, Less adjustable for range of use | Offers flexibility, very adjustable to range o |
| **Application** | Audio and Video transmission | Computing and Digital Electronics |
| **Instruments Application** | Give many observational errors | Never cause any observational errors |

**Terms Used:**

- **Bandwidth:** It is the difference between the upper and lower frequencies of a signal in a continuous band of frequencies. It is measured in Hertz (HZ)

- **Data Density:** More data means more data density. Higher frequencies are required to carry more data. Each carrier frequency has the data bit encoded, and the data transmitted per second is based on the active equipment's signal encoding scheme.

## Advantages and Disadvantages Digital Vs Analog Signal

### Analog Signal Advantage:

- Analog signal's prime advantage is the infinite data that they have.
- The data density is very high.
- These signals use less bandwidth.
- The accuracy is another advantage of Analog signals.
- Processing Analog signals is easy.
- They are less expensive.

### Analog Signal Disadvantage:

- The biggest disadvantage is distortion due to noise.
- The transmission rate is slow.
- The transmission quality is low.
- Data can be corrupted easily, and encryption is very difficult.
- Not easily portable, as analog wires are expensive.
- Synchronization is difficult.

## Digital Signal Advantage:

- Digital signals are reliable and distortion due to noise is negligible.
- They are flexible, and system upgrade is easier.
- They can be transported easily and are less expensive.
- The security is better and can be encrypted and compressed easily.
- The digital signals are easier to edit, manipulate, and configure.
- They can be cascaded without loading issues.
- They are free from observational errors.
- They can be stored easily in magnetic media.

## Digital Signal Disadvantage:

- Digital signals use high bandwidth.
- They require detection, require the communications system to be synchronized.
- Bit errors are possible.
- Processing is complex.

## Advantages of Digital Signal Over Analog Signal

Listed below are the few advantages of Digital Signal over Analog Signal:

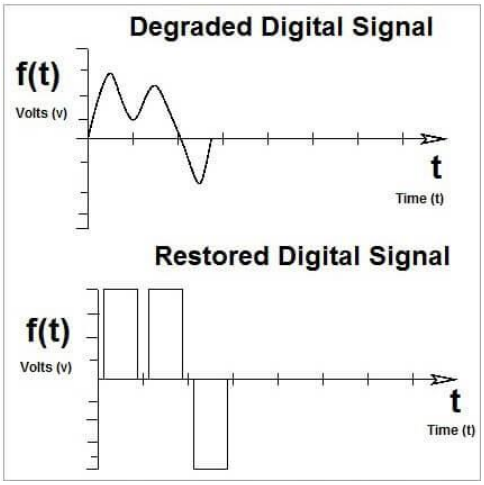
- Higher security.
- Negligible or zero distortion due to noise during transmission.
- The rate of transmission is higher.
- Multidirectional transmission concurrently and longer distance transmission is possible.
- Video, Audio, and Text messages can be translated into the device language.

## Degradation and Restoration of Digital Signals

The digital signals being a physical process exhibit degradation, but it is easy to clean up and restore the quality. Digital signals are either 0 or 1, so it is easy to understand from an eroded digital signal which is the zeros and ones, and restore them.

In the figure below, the points at each interval are adjusted to either zero or one, and the square wave is restored. These rounding off of the values to the nearest discreet value injects some error, but these are very small.

## Restoration of degraded digital signal:

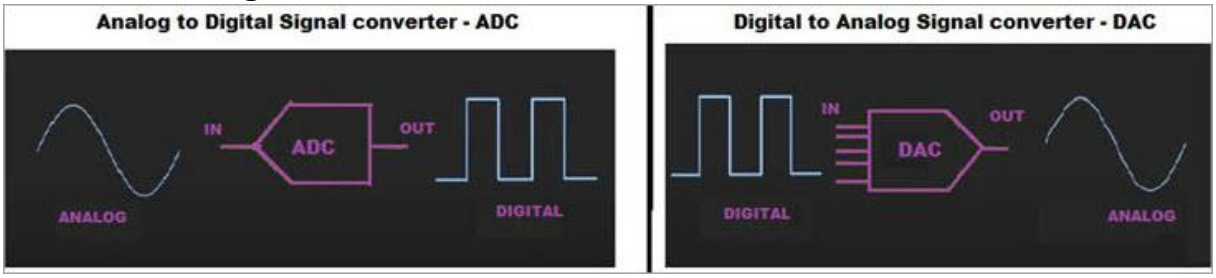



Analog signal restoration is not possible as the original value can be any value and hence cannot be restored to its actual original value. The practical implementation of digital transmission quality restoration is more complex. Just the core technology has been represented above.

## Converting Analog to Digital Signal and Vice-versa

Digital signals fulfilled the necessity of storing and retrieving the signals. But in order to listen or see the stored signal, the digitized signal had to be converted into analog signals. This is the reason we use analog-to-digital and digital-to-analog converters in many of our daily used apparatus like phones, TV, iPod, etc.

## ADC & DAC diagram:




## Analog-to-Digital Converter

ADC is an Analog-to-Digital converter. Continuous varying signal data is converted to discreet values at discreet time intervals using an ADC device. Like the highest peak of a sound wave is represented as the highest discreet value in the digital scale. Similarly, the analog value captured at the selected time interval is converted to the appropriate value on the digital scale.

These rounding off values to the appropriate discreet value on the digital scale injects conversion errors. But if the discreet values are selected properly, these deviation errors can be minimized.

While talking on our mobiles, the ADC in the phone converts what we speak from analog-to-digital signals. At the other end, in order to listen to the voice reaching the other microphone, DAC converts the digitized talk to analog signals for the person to listen.

**ADC Method:**

- The Pulse Code Modulation (PCM) method is used to convert analog-to-digital signals.
- Basically, Analog signal conversion has main 3 steps – **Sampling, Quantizing, Encoding**.
- Multiple discreet sample values are taken and a continuous signal stream is generated.
- A good sample rate (or sampling frequency) is required for good quality conversion.
- The sampling rate is the number of samples per unit (sec) taken from an analog signal that is continuous to convert it to a digital signal, which is captured at discreet time intervals.
- The sample rate differs from medium to medium. The sample rate of 8KHz for telephones, for VoIP rate of 16KHz, for CD and MP3 rate of 44KHz is considered good.
- **Sampling** gathers the variation of data into discreet time signals.
- The step of **quantizing** rounds of the amplitude of the sample gathered to a manageable number of levels that can be represented in binary orbit form.
- **Encoding** is done next to convert each value level at the specified discreet time intervals.
- The accuracy of the digital sample depends on the sampled analog signal. The sampling rate is a very important parameter that impacts the quality during the conversion of the analog-to-digital signals.
- Digital values take only discreet values, unlike analog signals. There can be a difference when the actual value has to be modified to the closest discreet value allowed in digital mode. This round-off done results in some deviation from the actual value and is referred to as the quantization error.
- So, the converted sample is always not the exact copy of the original signal.

## Digital-to-Analog Converter

DAC is a Digital-to-Analog converter. An abstract digital data stored needs to be converted to analog to be used in real life. These devices convert the binary digital code to a continuous analog signal. The music stored in a digital apparatus like iPod is in digital mode. In order to listen to the music, a DAC device is used to convert it to an analog signal.

The key factors impacting the conversion are the resolution, conversion time, and reference value.

- The resolution of DAC is the smallest output increment that it can produce.

- DAC settling time or conversion time is the time from the input code application until the output comes and is stable around the final value. A deviation from the final value within the allowed error band is accepted.
- The reference voltage (Vref) is the highest voltage value that the DAC can reach. The DAC chosen for audio output requires low frequency but a high resolution. Low resolution and high-frequency DAC are required for image, video, visual output.

## Analog Vs Digital Signal – Example Applications in Real Life

Let us take a real-life example to explain the Analog and Digital application in the system.

Original technology used in TV and Radio was analog. The brightness, volume, color was all represented by the value of the frequency, amplitude, and phase of the analog signal. Noise and interference made the signal weak and the final picture was snowy and the sound was very erratic. Digital signals paved the way to improving the quality.

In the debate, Analog vs digital Audio and Analog Vs Digital television, the digital signals have made an impeccable inroad. Digital signals have improved the quality of audio and videos in the new apparatus like mobile, computers, IPAD, Television, etc.

TV relay–The starting point is the camera where pictures are shot to be relayed. The lights captured by the sensors are analog. These are then converted to digital values. So, now the picture captured is represented as streams 0 and 1. Now the next step is to transmit the image from the TV station to our home TV.

The transmission is over cable if the connection in the case is of cable else it is transmitted through the air. For this transmission, the digitized signals are converted to analog. After the analog signal reaches our home, it is converted to digital for the home TV set to display the picture on the screen. To reach us it is converted to analog so that the light can reach us to view the image.

In real-life applications, this basic inter looping between digital and analog happens for us to get the message in our computers, HD television, digital phones, camera, etc. All the discussed phenomenon of signal distortion impacting the image and sound and their restoration is applied in these apparatuses.

TV Relay from picturization to viewing at home