

Analogue signals

An analogue signal uses some attribute of the medium to convey the signal's information. For example, an [aneroid barometer](#) uses the [angular position](#) of a needle as the signal to convey the information of changes in [atmospheric pressure](#).^[2] Electrical signals may represent information by changing their voltage, current, frequency, or total charge. Information is converted from some other physical form (such as sound, light, temperature, pressure, position) to an electrical signal by a [transducer](#) which converts one type of energy into another (e.g. a [microphone](#)).^[3]

In the real world, are all signals analogue?



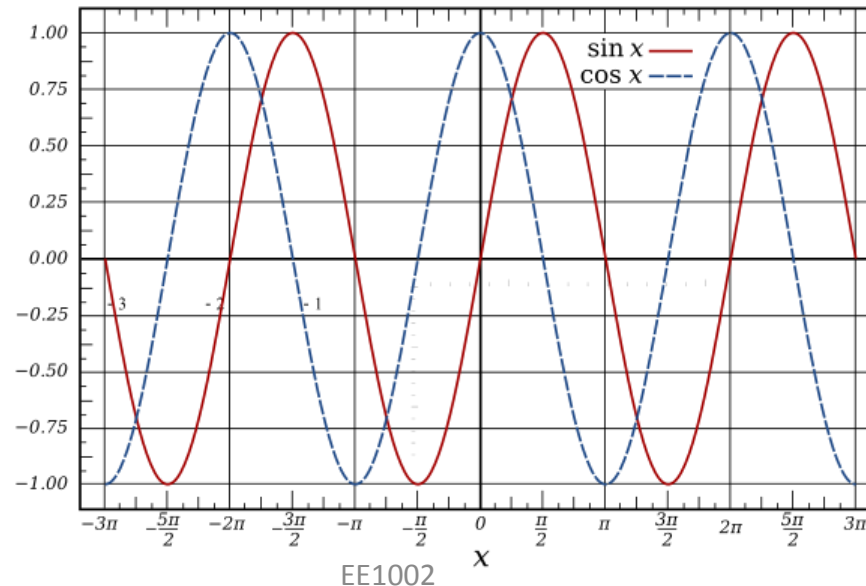
Analogue electronics

Analogue electronics (or **analog** in American English) are electronic systems with a continuously variable signal, in contrast to digital electronics where signals usually take only two levels. The term "analogue" describes the proportional relationship between a signal and a voltage or current that represents the signal.

https://en.wikipedia.org/wiki/Analogue_electronics

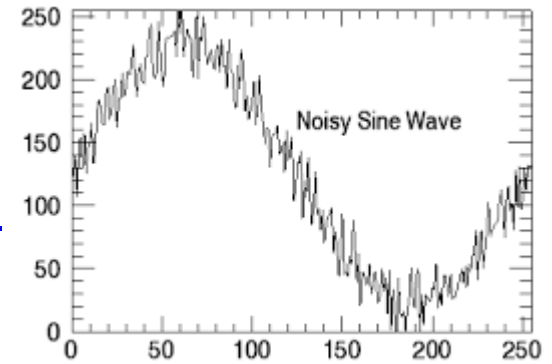
Analogue electronics

Another method of conveying an analogue signal is to use [modulation](#). In this, some base carrier signal has one of its properties altered: [amplitude modulation](#) (AM) involves altering the amplitude of a sinusoidal voltage waveform by the source information, [frequency modulation](#) (FM) changes the frequency. Other techniques, such as [phase modulation](#) or changing the phase of the carrier signal, are also used. [\[4\]](#)



Inherent noise

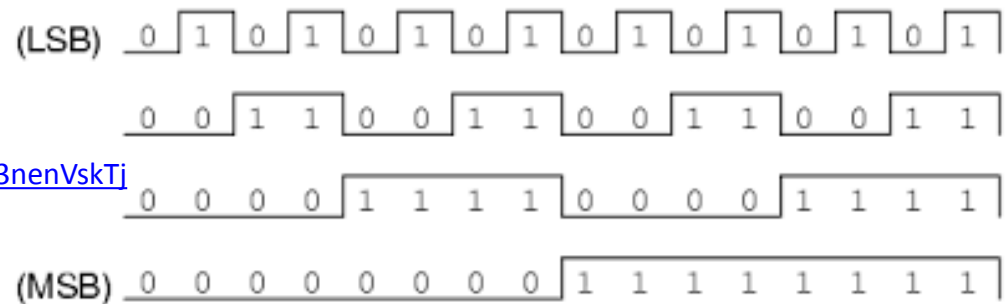
Analogue systems invariably include [noise](#) that is random disturbances or variations, some caused by the random thermal vibrations of atomic particles. Since all variations of an analogue signal are significant, any disturbance is equivalent to a change in the original signal and so appears as noise.^[5] As the signal is copied and re-copied, or transmitted over long distances, these random variations become more significant and lead to signal degradation. Other sources of noise may include external electrical signals or poorly designed components.



Digital electronics

Digital electronics, are [electronics](#) that represent [signals](#) by discrete bands of [analog levels](#), rather than by [continuous](#) ranges. All levels within a band represent the same signal state.

Digital techniques are useful because it is easier to get an electronic device to switch into one of a number of known states than to accurately reproduce a continuous range of values. https://en.wikipedia.org/wiki/Digital_electronics

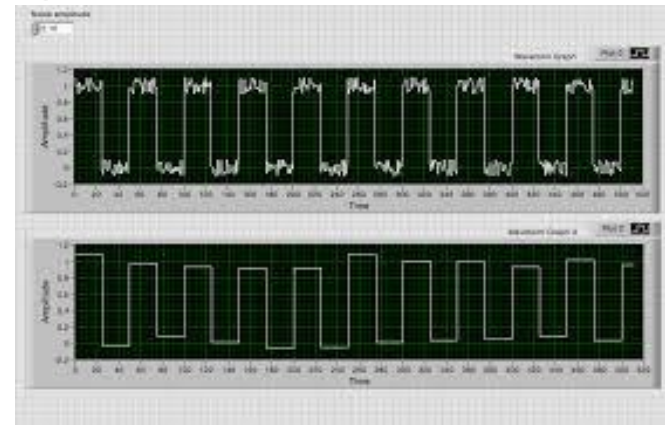


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Advantages

An advantage of digital circuits when compared to analog circuits is that signals represented digitally can be transmitted without degradation due to noise.^[2] For example, a continuous audio signal transmitted as a sequence of 1s and 0s, can be reconstructed without error, provided the noise picked up in transmission is not enough to prevent identification of the 1s and 0s. An hour of music can be stored on a compact disc using about 6 billion binary digits.

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Advantages

In a digital system, a more precise representation of a signal can be obtained by using more binary digits to represent it. Since each digit is handled by the same kind of hardware, resulting in an easily scalable system.

Information storage can be easier in digital systems than in analog ones. The noise-immunity of digital systems permits data to be stored and retrieved perfectly as long as the total noise is below a certain level.

In an analog system, noise from aging and wear degrade the information stored.

Advantages

Analogue circuits are typically harder to design, requiring more skills, than comparable digital systems. This is one of the reasons why digital systems have become more common than analogue devices.

An analogue circuit must be designed by hand, and the process is much less automated than for digital systems.

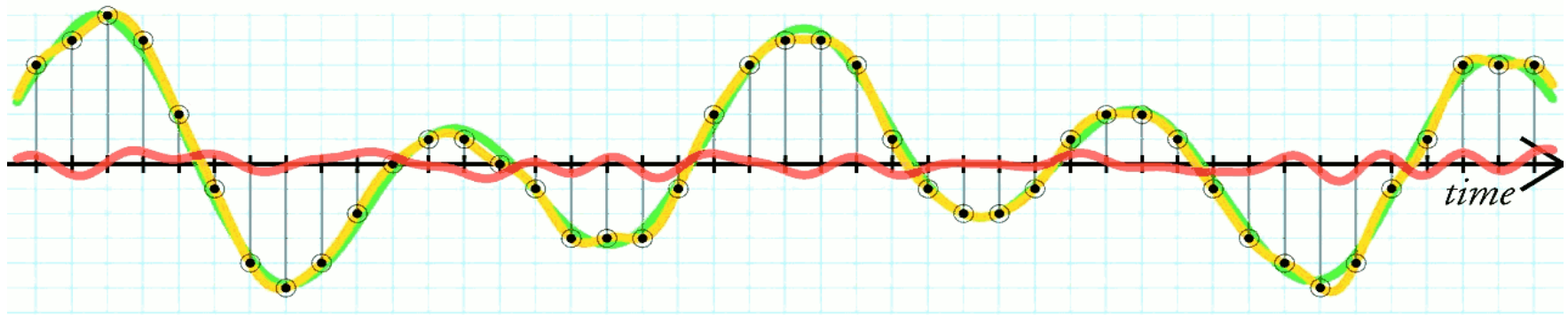
Example: VHDL (VHSIC Hardware Description Language) is a hardware description language used in electronic design automation to describe digital and mixed-signal systems such as field-programmable gate arrays and integrated circuits.

Disadvantages

Digital circuits sometimes use more energy than analog circuits to accomplish the same tasks, thus producing more heat.

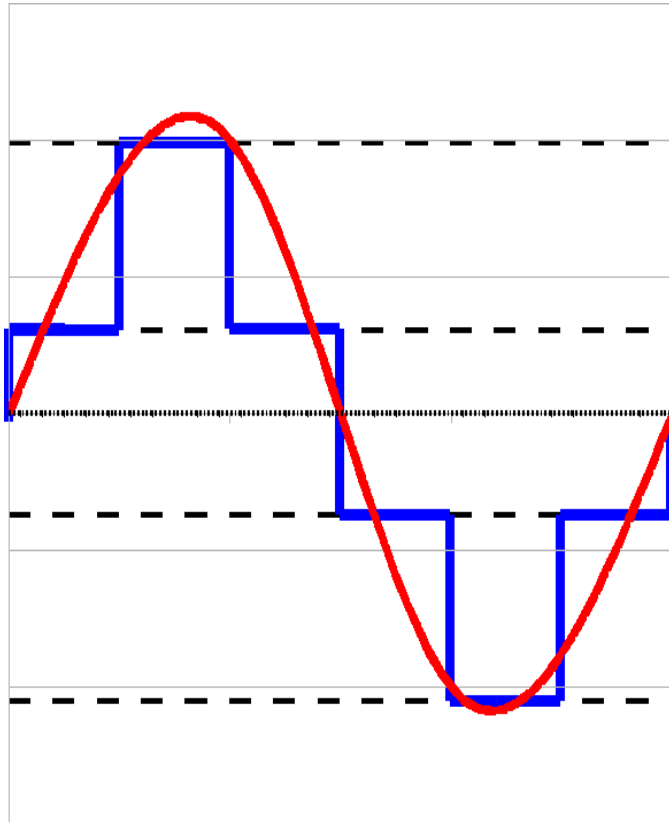
Most useful digital systems must translate from continuous analog signals to discrete digital signals. This causes quantization errors. Quantization error can be reduced if the system stores enough digital data to represent the signal to the desired degree of fidelity.

original signal
quantized signal
quantization noise



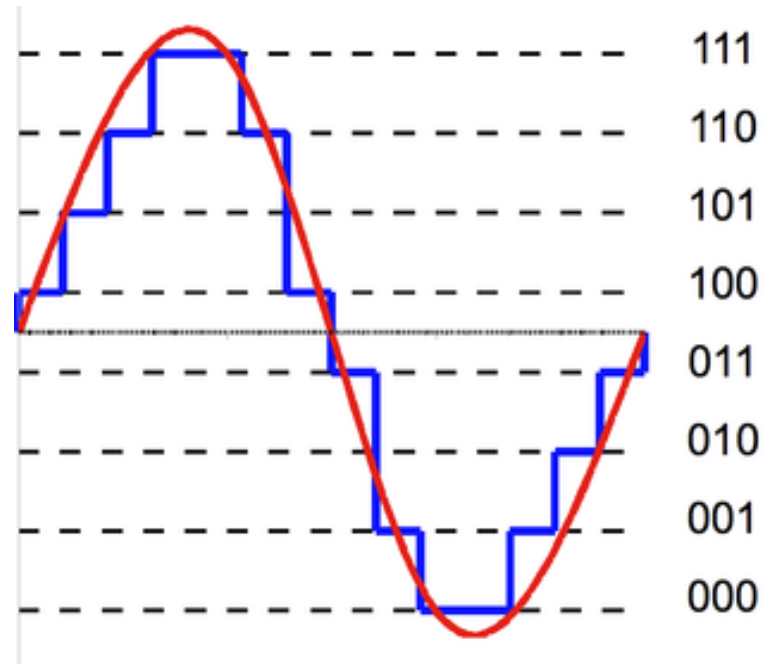
The simplest way to quantize a signal is to choose the digital amplitude value closest to the original analog amplitude. This example shows the original analog signal (green), the quantized signal (black dots), the signal reconstructed from the quantized signal (yellow) and the difference between the original signal and the reconstructed signal (red). The difference between the original signal and the reconstructed signal is the quantization error. https://en.wikipedia.org/wiki/Quantization_%28signal_processing%29

More Bits Better?



2-bit resolution with four levels

11
10
01
00



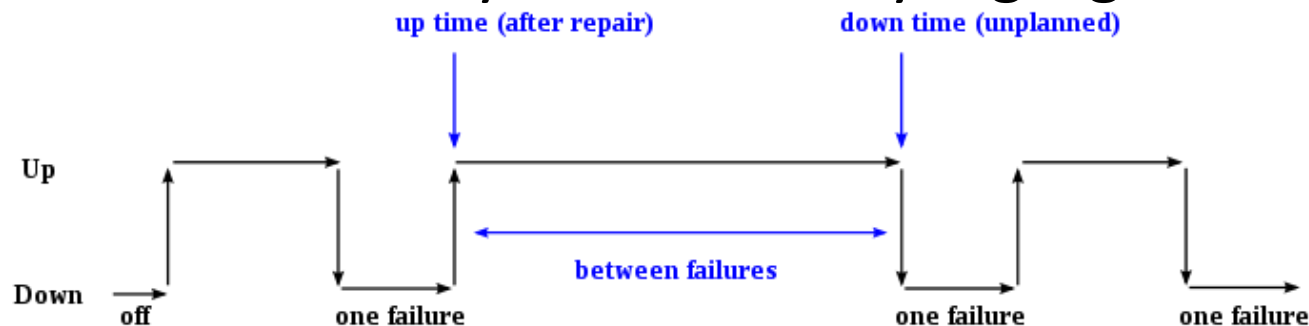
3-bit resolution with eight levels

Reliability

The "reliability" of a logic gate uses mean time between failure (MTBF). Digital machines often have millions of logic gates. Also, most digital machines are "optimized" to reduce their cost. The result is that often, the failure of a single logic gate will cause a digital machine to stop working.

https://en.wikipedia.org/wiki/Mean_time_between_failures

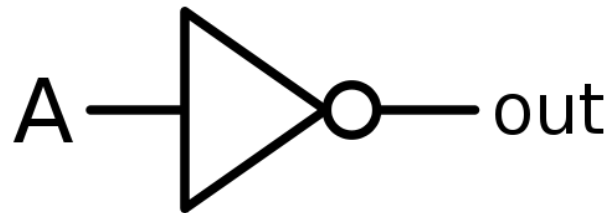
Modern transistorized integrated circuit logic gates have MTBFs greater than 82 billion hours (8.2×10^{10}) hours,^[7] and need them because they have so many logic gates.



$$\text{Time Between Failures} = \{ \text{down time} - \text{up time} \}$$

Speed

The "switching speed" describes how many times per second an inverter (an electronic representation of a "logical not" function) can change from true to false and back. Faster logic can accomplish more operations in less time. Modern electronic digital logic routinely switches at five [gigahertz](#) (5×10^9 hertz), and some laboratory systems switch at more than a [terahertz](#) (1×10^{12} hertz).



https://en.wikipedia.org/wiki/Inverter_%28logic_gate%29

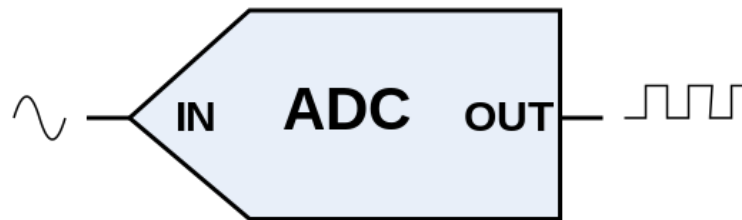
Interface to the real world

However, if a digital electronic device is to interact with the real world, it will always need an analogue interface.^[9] For example, every [digital radio](#) receiver has an analogue preamplifier as the first stage in the receive chain.

Interface to the real world

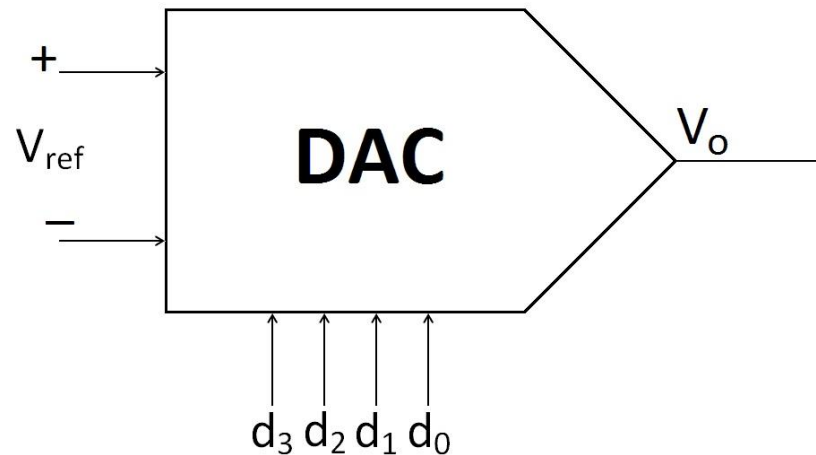
An **analog-to-digital converter (ADC, A/D, or A to D)** is a device that converts a continuous physical quantity (usually voltage) to a digital number that represents the quantity's amplitude.

The conversion involves quantization of the input, so it unavoidably introduces a small amount of error. An ADC often performs the conversions ("samples" the input) periodically. The result is a sequence of digital values that have been converted from a continuous-time and continuous-amplitude analog signal to a discrete-time and discrete-amplitude digital signal.



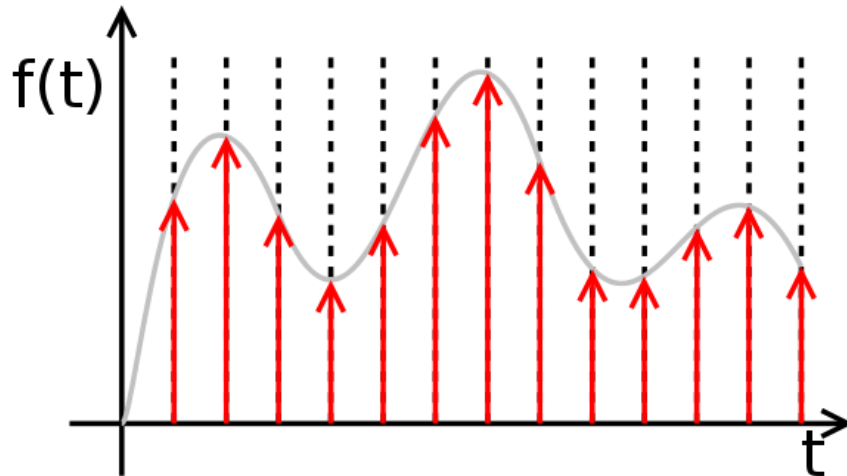
Digital-to-analog converter

A **digital-to-analog converter (DAC, D/A, D2A or D-to-A)** is a function that converts digital data (usually binary) into an analog signal (current, voltage, or electric charge).

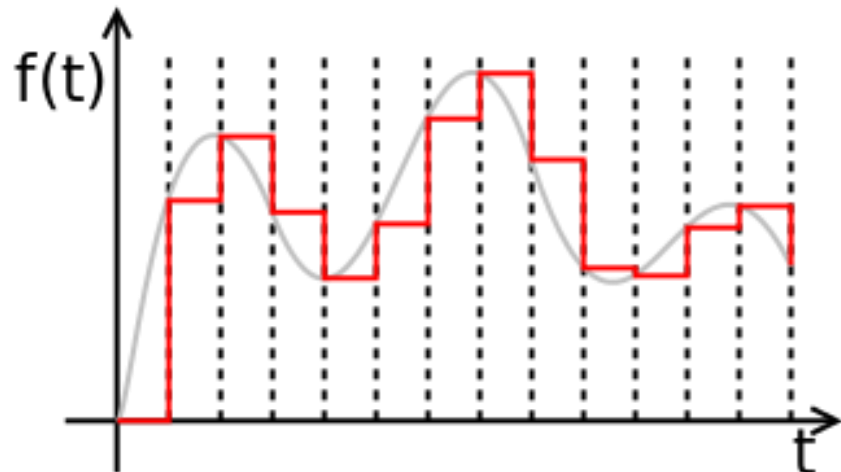


https://upload.wikimedia.org/wikipedia/commons/5/5f/DAC_Symbol.jpg

ADC and DAC



ADC sample the signal



DAC output to reconstruct the signal

https://en.wikipedia.org/wiki/Digital-to-analog_converter

Compact Disc Digital Audio

Encoding format: 2 channels of LPCM audio, 16-bit values sampled at 44100 Hz https://en.wikipedia.org/wiki/Compact_Disc_Digital_Audio

$2 * 44.1k * 16 = 1,411,200$ bits per second or $176,400$ bytes per second. (Uncompressed audio format).

i.e. For 60 minutes of music

$1,411,200 * 60 * 60 = 5,080.32$ Mbit + error correction code
= around 6 billion bits

For 1 minute = around 12 Mbyte

Or = around 1.5 Mbyte/sec or 12Mbit/sec

For a song of 4 minutes = around 48 Mbyte

One CD (700MB) can store around 60+ minutes of music

Error correction codes

What is error correction codes?

In [information theory](#) and [coding theory](#) with applications in [computer science](#) and [telecommunication](#), **error detection and correction** or **error control** are techniques that enable reliable delivery of [digital data](#) over unreliable [communication channels](#). Many communication channels are subject to [channel noise](#), and thus errors may be introduced during transmission from the source to a receiver. Error detection techniques allow detecting such errors, while error correction enables reconstruction of the original data in many cases.

Lossy Digital Audio Snap Shot

The actual audio [bit rate](#) for an audio CD is 1,411,200 [bits per second](#) or 176,400 [bytes per second](#).

Example: An MP3 file using the setting of 128 [kbit/s](#) is about 1/11 the size of the [CD](#) file. Because $1,411,200 / 128,000 = 11.025$). Significantly smaller File.

An MP3 file can also be constructed at higher or lower bit rates, with higher or lower resulting quality.

<https://en.wikipedia.org/wiki/MP3>

There are many other Codecs available, eg. AAC, ...
CDs are being replaced by other storage medium.

Lossless compressed audio format

A lossless compressed format stores data in less space without losing any information. The original, uncompressed data can be recreated from the compressed version.

Uncompressed audio formats encode both sound and silence with the same number of bits per unit of time. Encoding an uncompressed minute of absolute silence produces a file of the same size as encoding an uncompressed minute of music. In a lossless compressed format, the silence would take up almost no space at all.

Lossless compressed audio format

Lossless compression formats include the common^[6] [FLAC](#), [WavPack](#), [Monkey's Audio](#), [ALAC](#) (Apple Lossless). They provide a compression ratio of about 2:1 (i.e. their files take up half the space of PCM).

Development in lossless compression formats aims to reduce processing time while maintaining a good compression ratio.

Lossless compressed audio format

How about the sound quality of different lossless audio codec? Which one is better in terms of sound quality?

A **codec** is a device or [computer program](#) capable of [encoding](#) or [decoding](#) a [digital data stream](#) or [signal](#).^{[1][2][3]}

A codec encodes a data stream or signal for transmission, storage or [encryption](#), or decodes it for playback or editing. Codecs are used in [videoconferencing](#), [streaming media](#) and [video editing](#) applications. <https://en.wikipedia.org/wiki/Codec>

Lossless compressed audio format

Why use lossy codec?

Do the decreasing cost of storage capacity and network bandwidth affecting the use of lossy codec?