Work-Ready Electronics

Synchronizing Curriculum to the Rapidly Changing Workplace

Module: Data Conversion, Part 1
Digital-to-Analog Conversion

WORKREADY ELECTRONICS

Data Conversion, Part 1

This module is the first of two covering data conversion techniques, specifically digital-to-analog conversion (DAC) and analog-to-digital conversion (ADC).

This module reviews basic concepts and methods and provides an overview of the rationale, need, and terminology. It covers the fundamentals of digital-to-analog conversion, introduces the newest methods, describes the critical specifications, and introduces typical integrated circuits (ICs) and applications.

The second module (Part 2) covers analog-to-digital conversion (ADC) and introduces new techniques, typical specifications, and applications.

What Technicians Need to Know

Two types of data conversion

Key reasons why data conversion is needed

Nyquist theory

Aliasing

R-2R, string, and switched current source methods of DAC

Major specifications of a DAC

Common DAC applications

Data Conversion Fundamentals

What is Data Conversion?

Data conversion is the process of converting analog signals into digital data and converting digital data into an analog signal.

Analog signals are voltages that vary smoothly and continuously over time. Examples include voice, music, video, and physical variations from sensors and transducers. A DC voltage is analog.

Analog-to-digital conversion is carried out by a circuit called an analog-to-digital converter or A/D converter (ADC).

Digital signals are usually binary voltages that switch between two voltage or current levels. Information is represented in the form of multi-bit binary numbers or codes.

Digital-to-analog conversion is carried out by a circuit called a digital-to-analog converter or D/A converter (DAC).

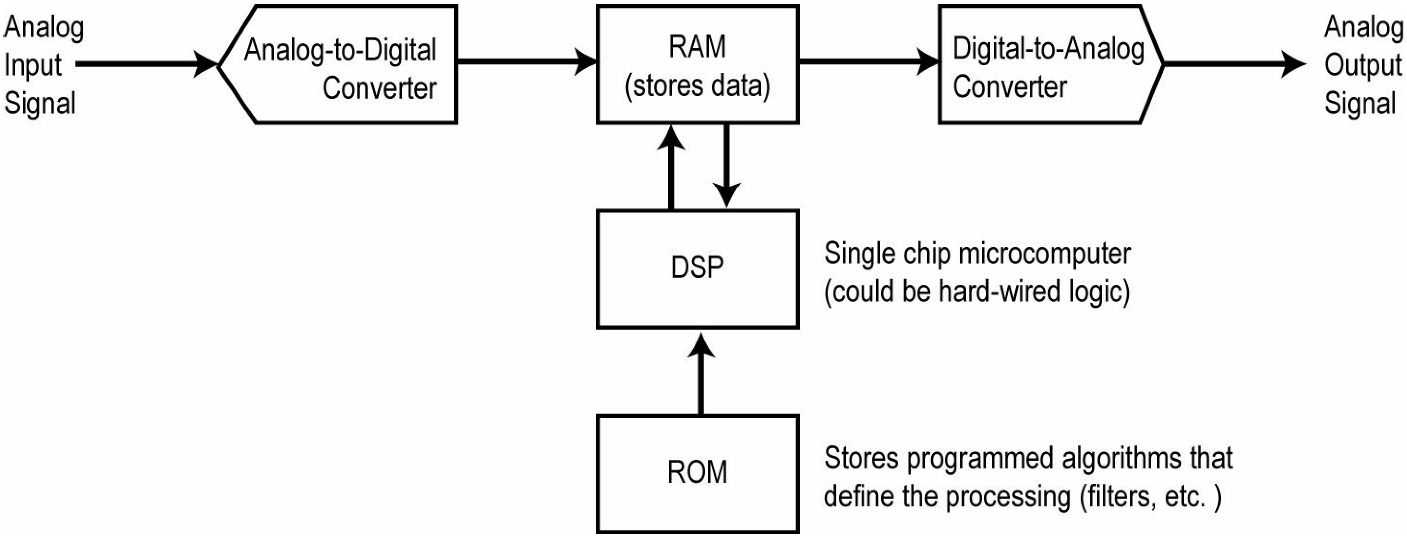
The Need for Data Conversion

In the past, analog signals were manipulated and processed with either analog or linear circuits like amplifiers, filters, mixers, or modulators/demodulators. Even though analog processing is still widely used, it has been largely replaced in electronic equipment.

The discovery and the low cost implementation of digital signal processing (DSP) has made digital processing both cheap and convenient. The availability of fast, very low cost microprocessors used in digital signal processing offers significant benefits over analog processing methods.

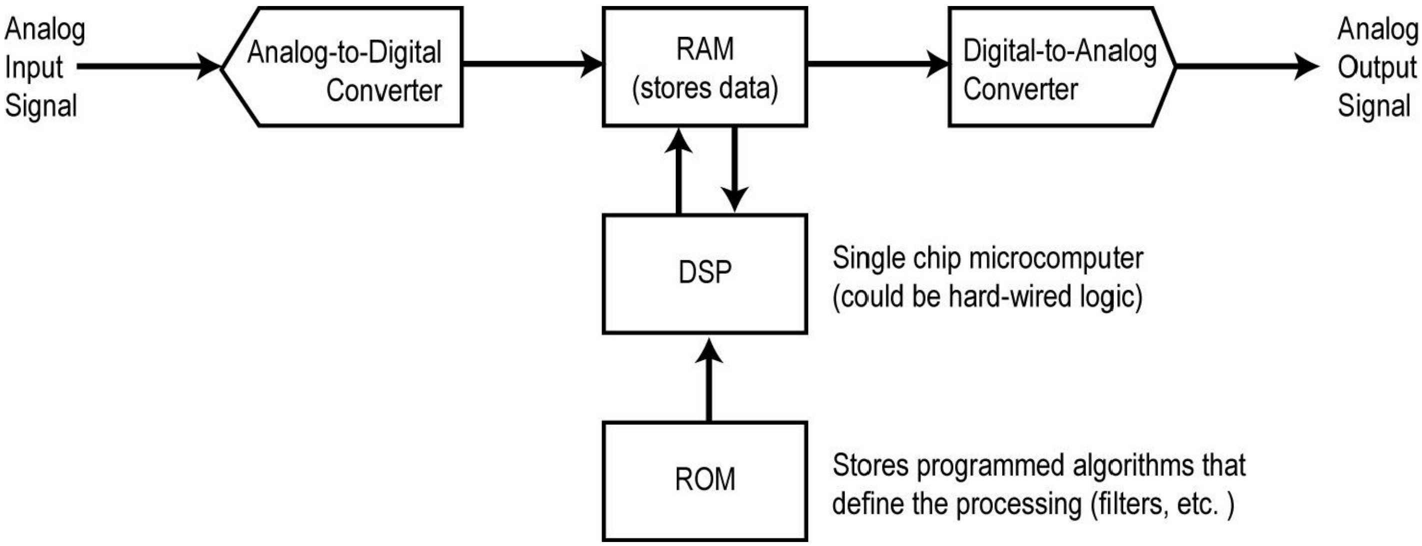
Some form of data conversion is necessary to put analog signals into digital form and then convert them back to analog after processing.

Digital Signal Processing



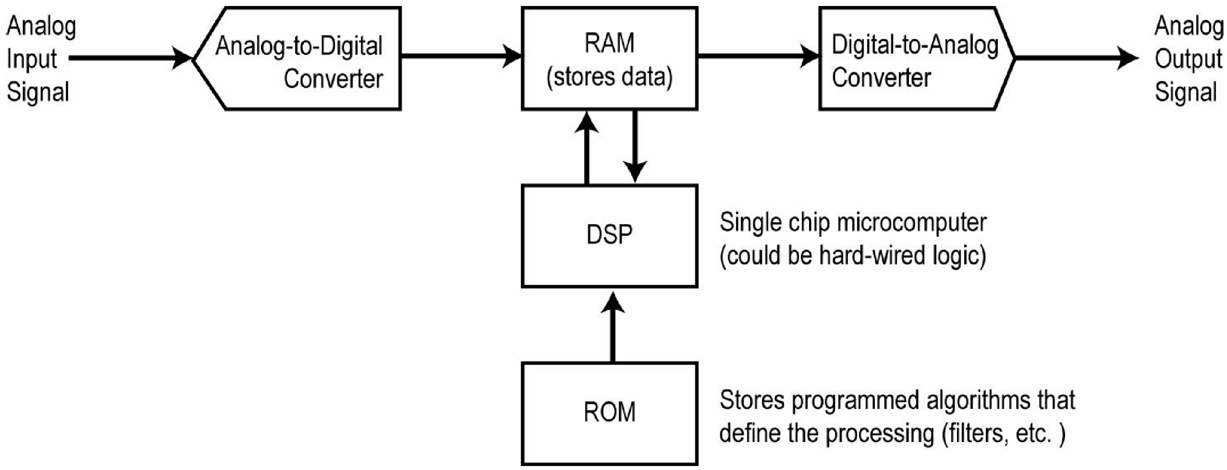
A discussion of this graphic is presented in the pages that follow. You can print this graphic for study purposes before going on.

Digital Signal Processing



Digital signal processing (DSP) is used in virtually all electronic applications. It replaces most of the previously analog processing such as filtering, modulation, and demodulation.

Digital Signal Processing



The analog signal is digitized by an ADC and stored in RAM. The digital data is then processed by the digital signal processor. The DSP is usually a specialized microcomputer on a chip.

The processing is defined by algorithms that are programmed and stored in the DSP ROM and executed by the DSP. The digital output is stored in RAM.

The RAM output is sent to a DAC that converts the processed output back to analog form for use.

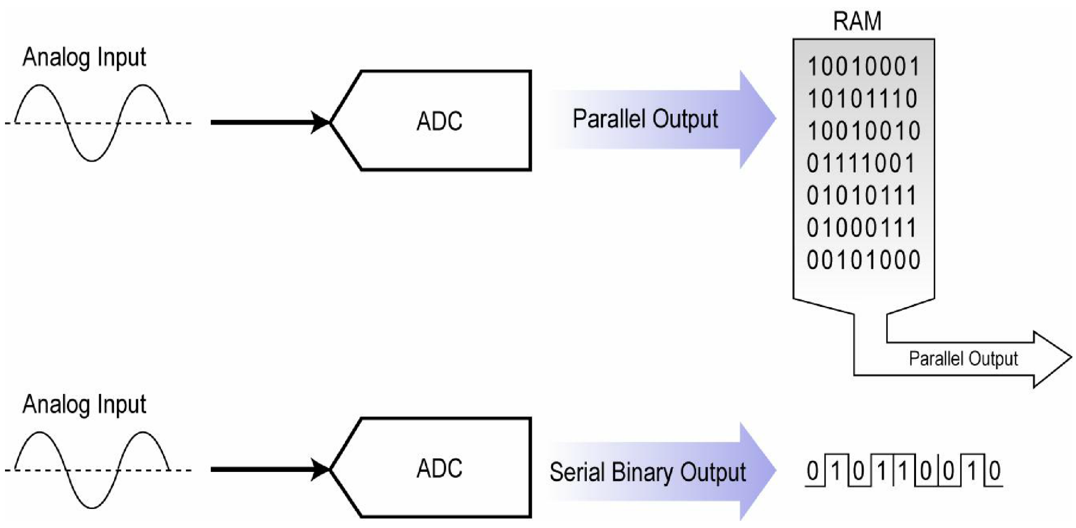
Benefits of Digital Processing

Analog signals are more easily stored and reliably communicated if they are first converted to digital. Storage may be in semiconductor memory, hard disk drive, optical (CD) media, or some other form. Digital signals are more immune to noise and transmission errors.

One benefit of digital signal processing is that improved performance can be achieved. For example, digital filters can be specifically tailored to the application and provide improved selectivity and dynamic range.

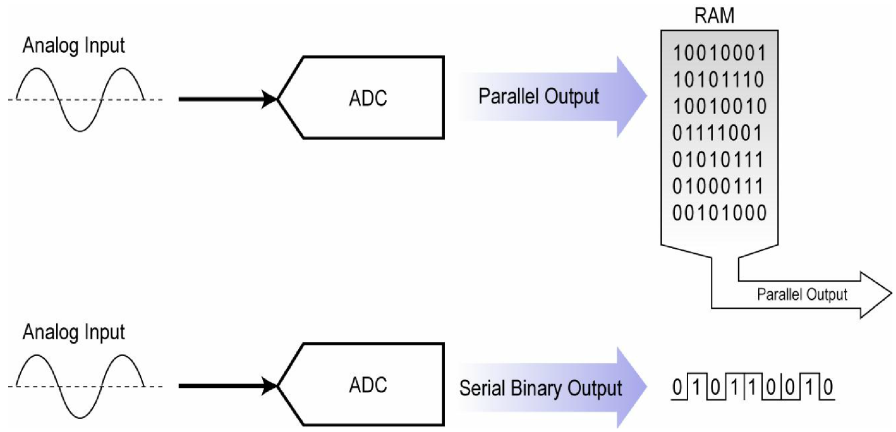
DSP is easily carried out by software algorithms that are executed on low cost, high speed microprocessors designed for digital signal processing. These microprocessors are referred to as digital signal processors. The processing is defined by software not hardware.

Analog-to-Digital Conversion



A discussion of this graphic is presented in the pages that follow. You can print this graphic for study purposes before going on.

Analog-to-Digital Conversion



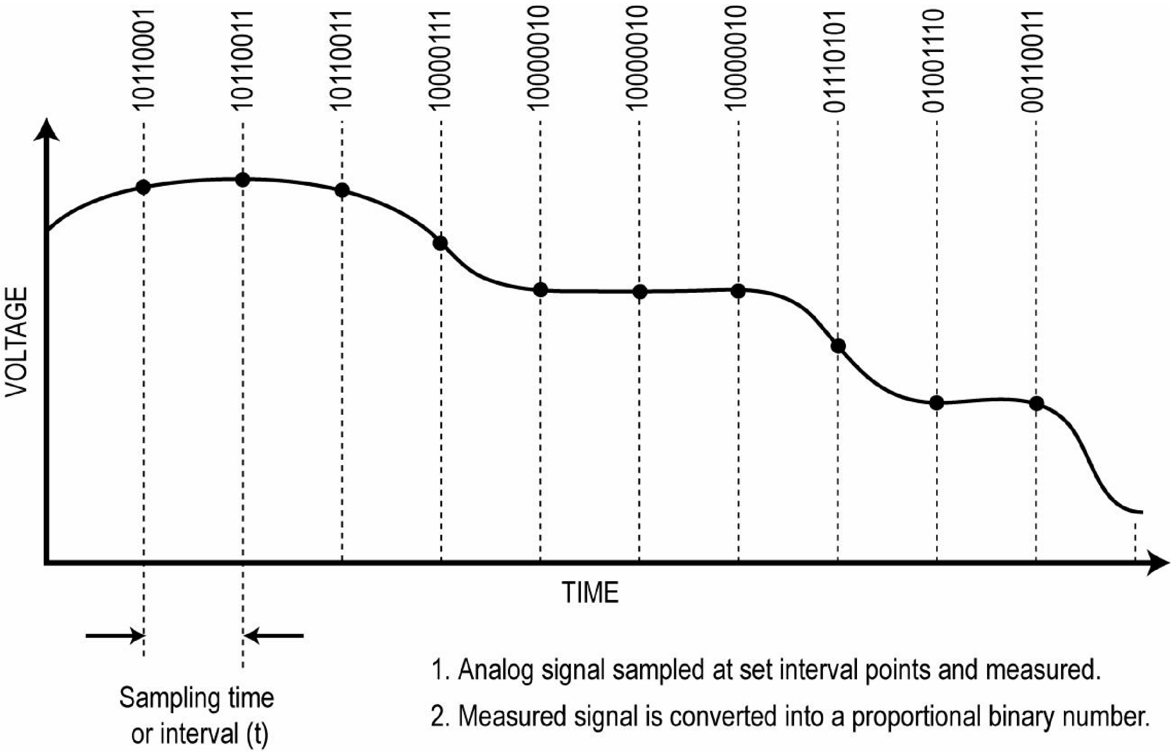
Analog-to-digital conversion is the process of taking an analog signal and converting it into a sequence of fixed length and proportional binary numbers.

The term digitize is often used to describe the ADC process.

The binary numbers are processed, stored, and/or transmitted digitally.

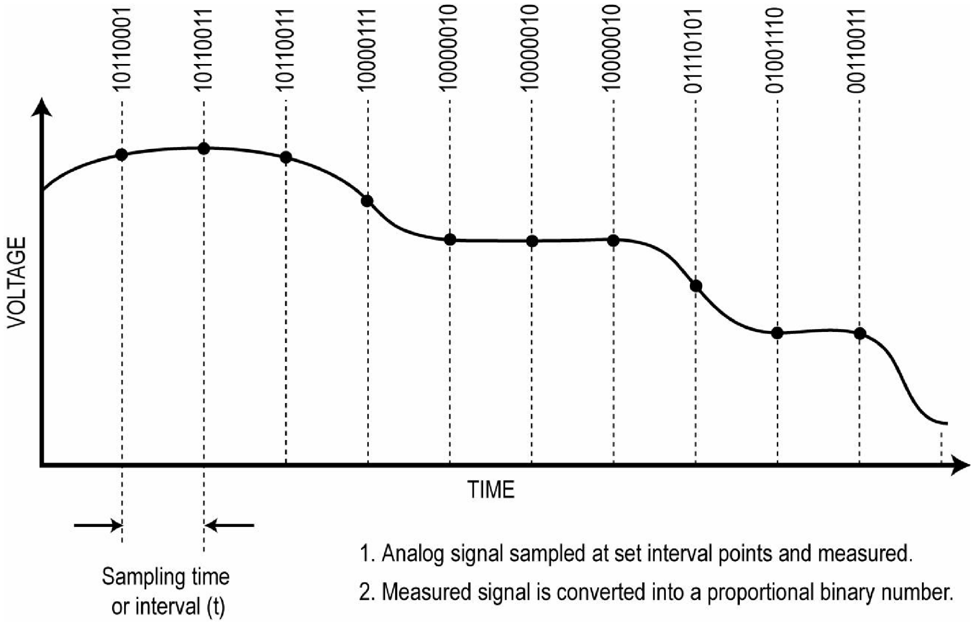
The generic block shown here is used to represent an analog-to-digital converter (ADC). The input is an analog signal. The output is a sequence of parallel binary words. Some ADCs produce a serial binary output.

The ADC Process



A discussion of this graphic is presented in the pages that follow. You can print this graphic for study purposes before going on.

The ADC Process

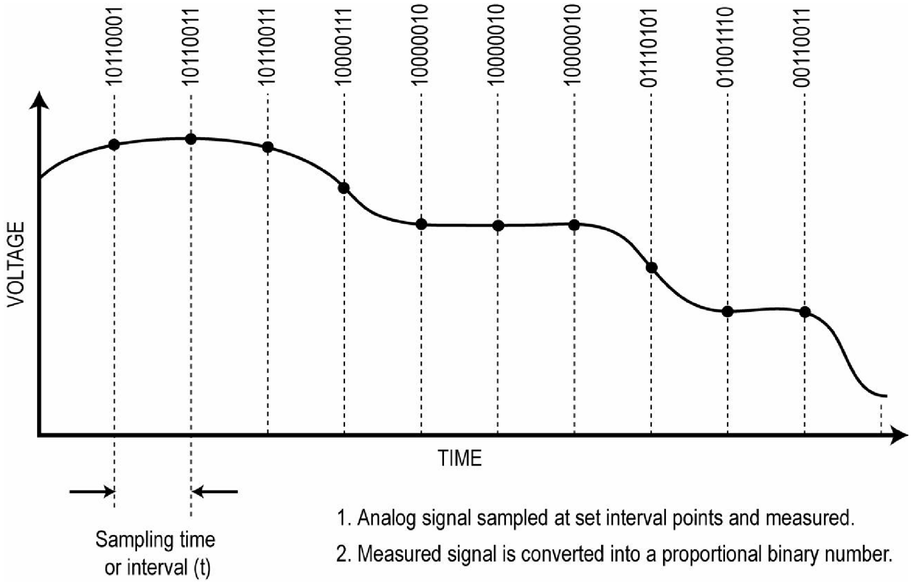


The two basic parts to ADC are sampling and quantization.

Sampling means measuring the analog signal for a short instant at fixed time intervals.

Quantization means converting the measured sample voltage into a proportional binary code.

The ADC Process



The analog signal is repeatedly sampled at fixed intervals. Each vertical line represents a sample that is ultimately converted into a binary number.

The key to preserving the information content of the analog signal is to sample as frequently as possible and to use an ADC with good quantization resolution.

The Nyquist Theorem

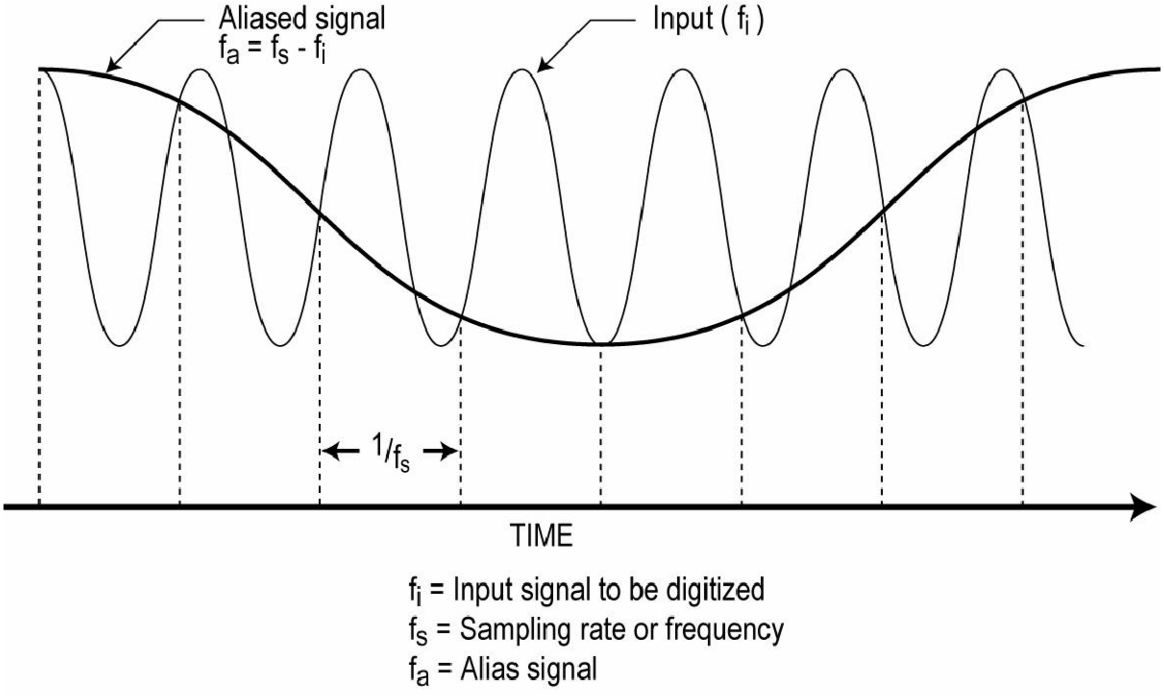
The Nyquist theorem, also called the sampling theorem, states that the information in an analog signal will be accurately preserved if it is sampled at a rate at least two times the highest frequency component of the signal.

For example, voice signals usually contain frequencies up to about 3 kHz. To convert voice into digital, the analog voice signal should be sampled (e.g. converted) at a minimum rate of 6 kHz. Most voice is actually sampled at an 8 kHz rate.

Music normally contains frequencies as high as 20 kHz at the upper limit of human hearing. To preserve this information, the sampling rate must be at least 2 x 20 kHz = 40 kHz. The sampling rate for a music compact disk (CD) is 44.1 kHz.

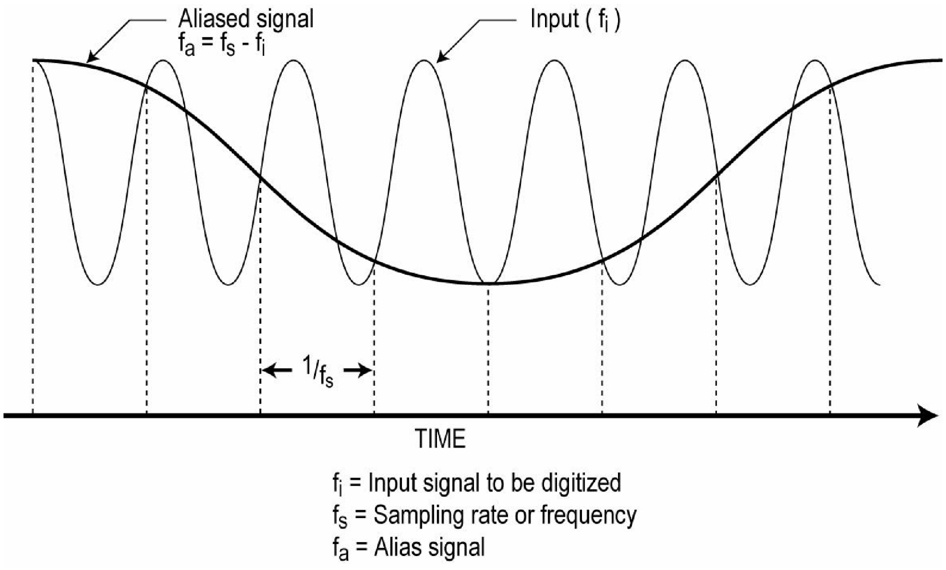
The sampling interval (t) is the reciprocal of the sampling rate (f_s). $t = 1/f_s$ For an 8 kHz rate, the sampling time interval is 125 μS.

Aliasing



A discussion of this graphic is presented in the pages that follow. You can print this graphic for study purposes before going on.

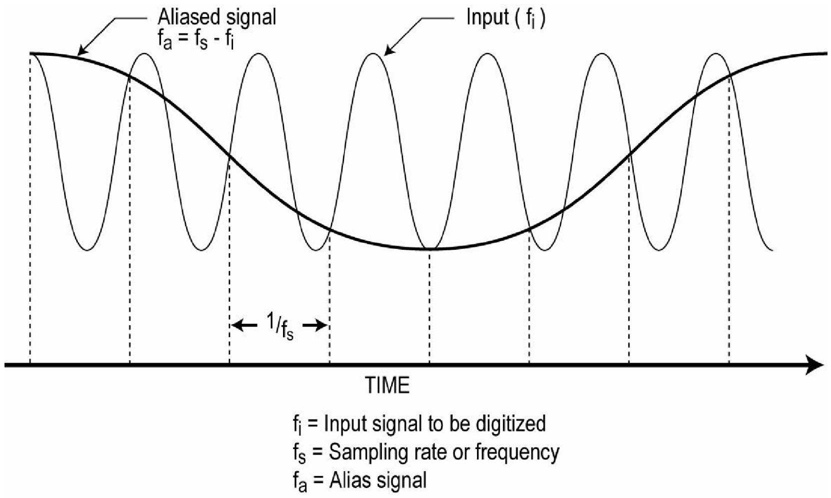
Aliasing



Aliasing is a conversion error that occurs if the analog signal is not sampled at a sufficient rate.

When the digital signal is converted back into an analog signal a new, different signal results. The alias frequency is different from the original signal frequency.

Aliasing



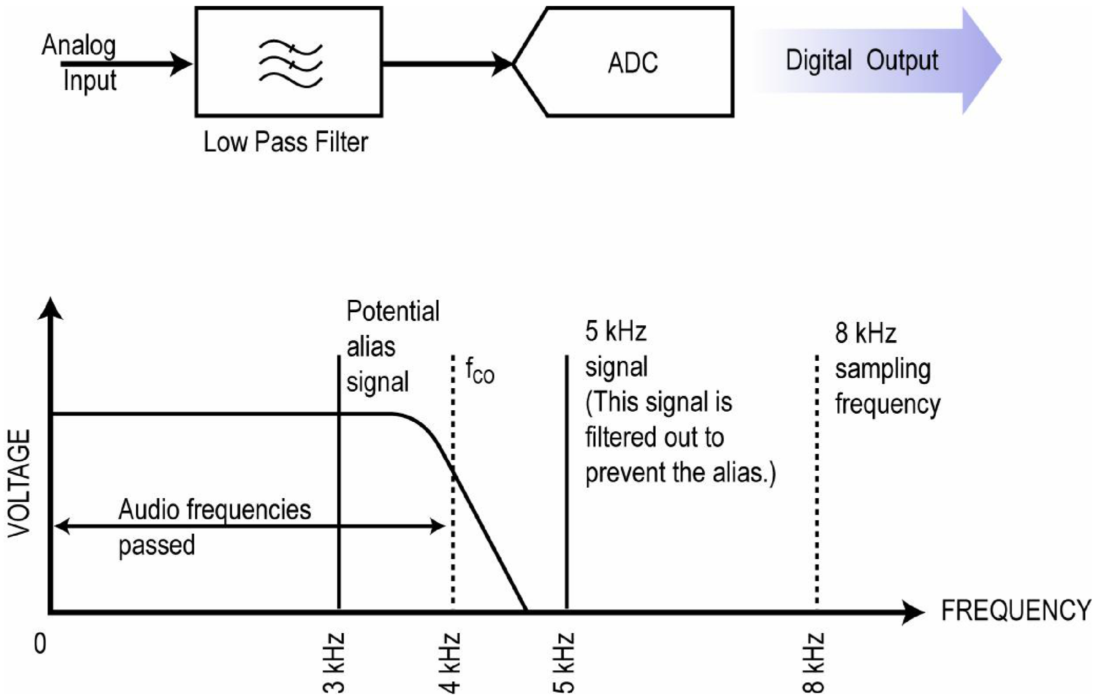
The signal (f_i) is shown sampled at a rate below the desired Nyquist rate. When converted back to analog, the result is the second, or alias signal (f_a).

The alias frequency f_a is equal to the sampling frequency f_s less the frequency or the original signal (f_i).

$$f_a = f_s - f_i$$

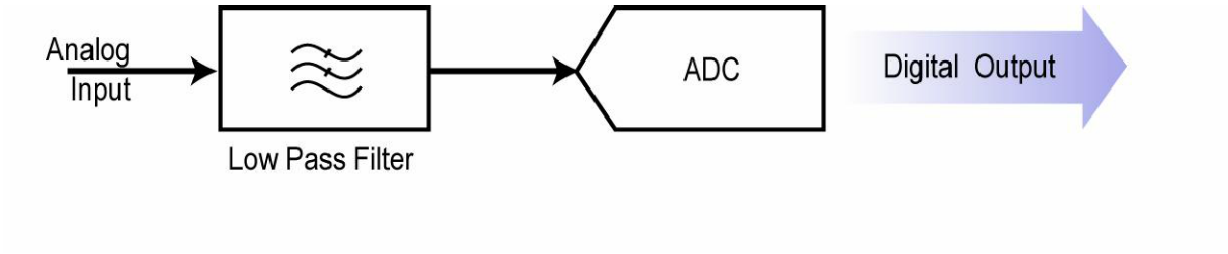
If a 5 kHz audio signal is sampled at 8 kHz, digitized, and then converted back to an analog signal, the DAC output would be 8 kHz – 5 kHz = 3 kHz.

Preventing an Alias



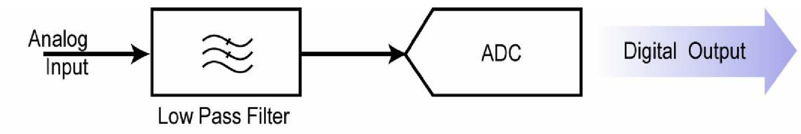
A discussion of this graphic is presented in the pages that follow. You can print this graphic for study purposes before going on.

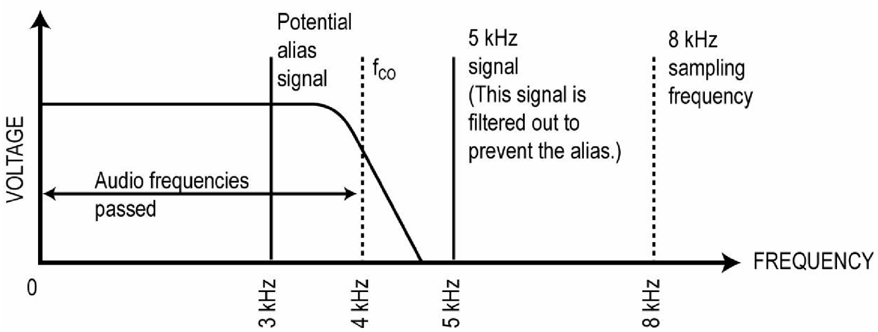
Preventing an Alias



Aliasing is prevented by placing a low pass filter between the analog signal and the ADC input. The cutoff frequency is set to a frequency slightly above the highest frequency content in the input.

Preventing an Alias





In the earlier 5 kHz audio signal example, the sampling rate of 8 kHz means that the absolute maximum input signal must be less than 4 kHz.

The low pass filter cut off frequency (f_{co}) is set to 4 kHz to filter out the 5 kHz signal. This eliminates the 3 kHz alias signal that could cause interference with the other audio signals passed by the filter.

Resolution

Resolution refers to the fineness of amplitude definition or representation.

The input range of an ADC is defined by its design. The analog voltage range is effectively divided up into equal increments of voltage. Each increment is represented by a binary number.

The resolution is defined by the number of bits in the binary number and is equal to 2^N where N is the number of bits.

Resolution Example

If an ADC has an 8-bit output, then the input range is divided up into $2^N = 2^8 = 256$ steps or increments.

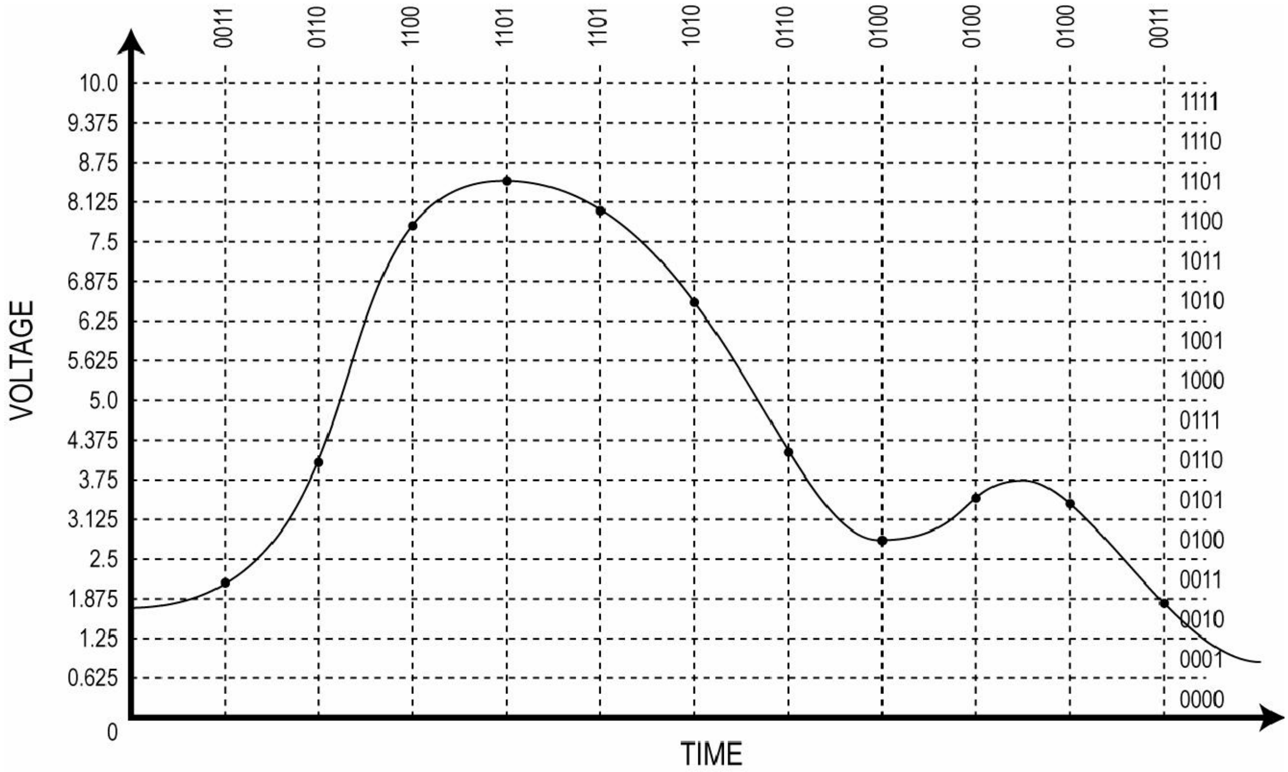
Resolution is sometimes expressed as a percentage or $(1/2^N)(100)$. In this example, (1/256)(100) = .0039 x 100 = .39 %

If the input voltage range is 0 to +5 volts, then each increment equals 5/256 = .01953 volts or 19.53 millivolts (mV).

The resolution is the smallest increment by a single bit change. It is the increment represented by the least significant bit (LSB).

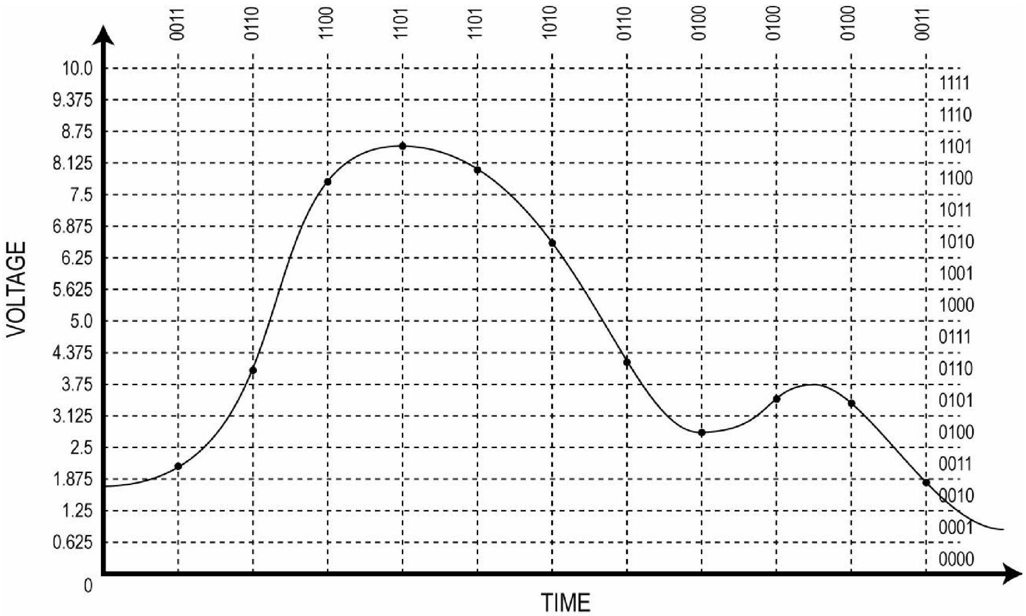
The greater the number of bits, the greater the resolution and the greater precision with which the analog signal is represented.

Analog-to-Digital Conversion Example



A discussion of this graphic is presented in the pages that follow. You can print this graphic for study purposes before going on.

Analog-to-Digital Conversion Example



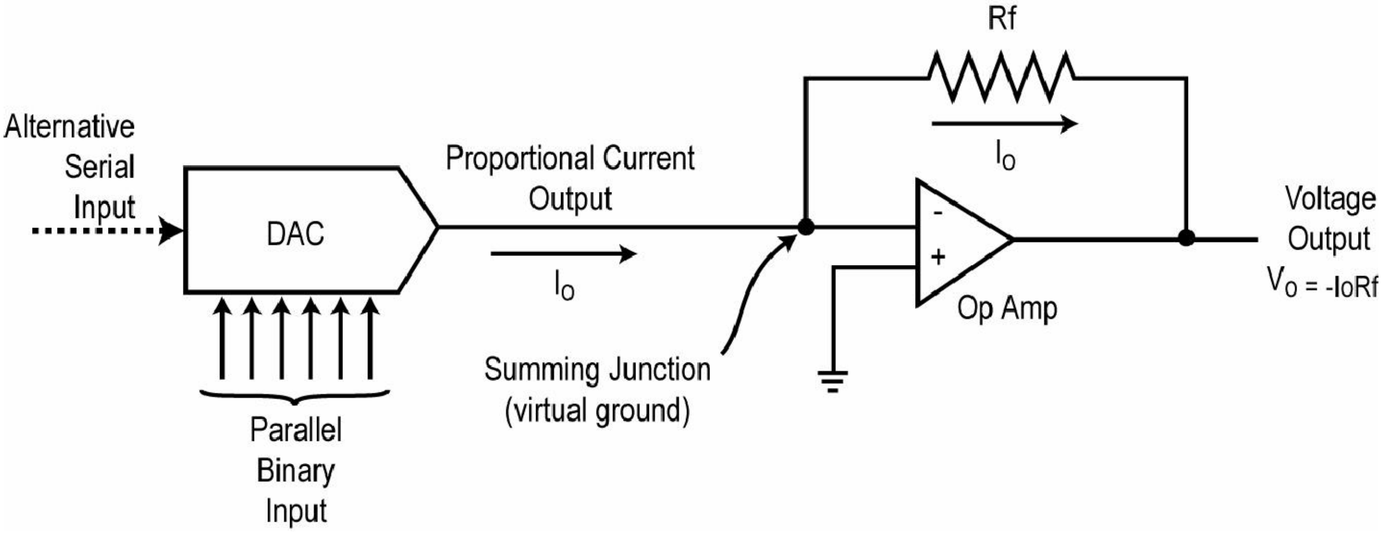
In this example, an analog signal is converted to 4-bit binary numbers.

The input voltage range is 0 to 10 volts.

The resolution is $2^N = 2^4 = 16$ steps or increments of 10/16 = 0.625 volts. Each increment is represented by a binary code .

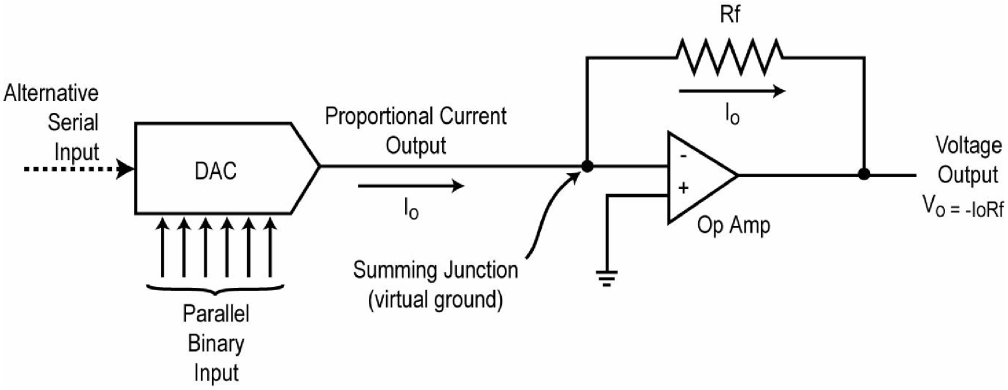
The output has 16 steps or increments 0 (0000) through 9.375 volts (1111).

Digital-to-Analog Conversion



A discussion of this graphic is presented in the pages that follow. You can print this graphic for study purposes before going on.

Digital-to-Analog Conversion



Digital-to-analog conversion is the process of converting a binary input number into a proportional analog voltage by using a digital-to-analog converter (DAC).

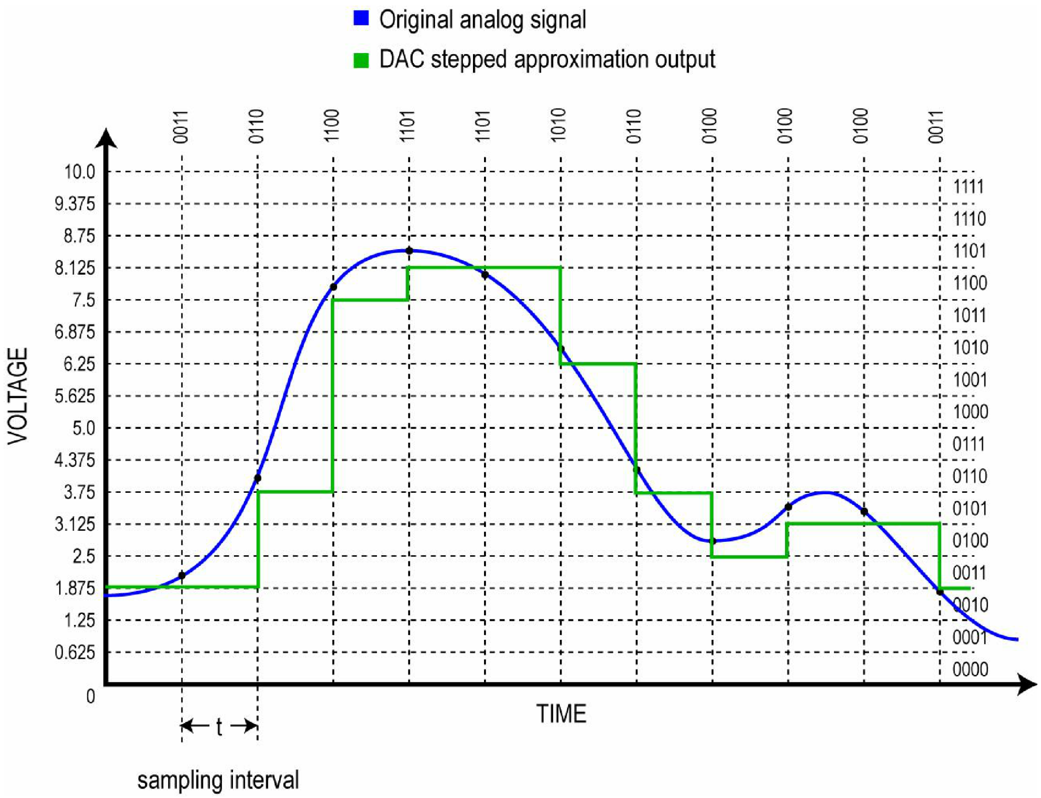
If the input to the DAC is a sequence of binary numbers, the DAC will produce an analog output level for each binary number.

This graphic is the symbol used to represent a DAC.

Some DACs have a parallel binary input of N bits while others have a serial input.

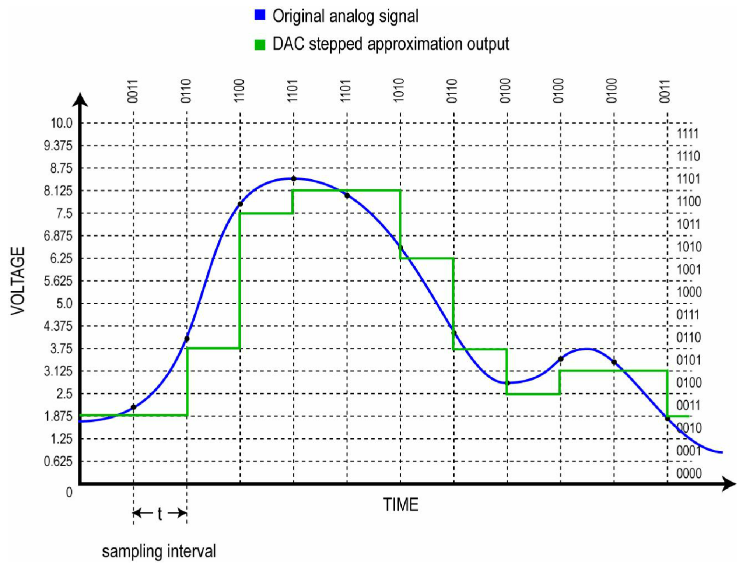
Most DACs have a current output and use an op amp to convert that current into a voltage.

D/A Conversion Example



A discussion of this graphic is presented in the pages that follow. You can print this graphic for study purposes before going on.

D/A Conversion Example



The DAC converts the binary codes from the A/D into the equivalent analog signal. The analog output is a stepped approximation of the original signal shown for comparison purposed. The binary numbers must be fed to the DAC at the original sampling rate if the original signal is to be reproduced.

As long as the Nyquist criterion is met, all analog content will be preserved.

A low pass filter may be used to smooth the stepped signal into a signal more closely representing the original analog signal although it is not always necessary.

Common Applications for Data Conversion

The telephone system is digital. The analog voice is sent from the phone over the twisted pair local loop cable to the central office (CO). At the CO, the voice is digitized at an 8 kHz rate into 8-bit binary numbers and transmitted serially to the dialed destination. The digital voice is then converted back to analog for transmission by analog over the local loop to the receiving telephone.

Common Applications for Data Conversion

Cell phones are mostly digital. The analog voice is digitized by an ADC and the resulting serial digital signal is transmitted by radio to the cell site where it is then sent to the CO for transmission elsewhere. The received signal in digital form is then sent by another cell site to the receiving phone. A DAC converts the voice back into analog sound at the handset. Most cordless telephones operate in similar manner.

Common Applications for Data Conversion

Most music is sold in digital form on a CD. The music is digitized by an ADC that samples at 44.1 kHz and records the data as 14-bit words on the disk.

There are actually two digital signals for stereo, left and right. At the CD player, a laser reads the binary signal and sends it to two DACs where it is converted back to analog before it is amplified for the speakers.

DVD sound is also digital and the process is similar to that described above only a 48 kHz sampling rate is used.

Common Applications for Data Conversion

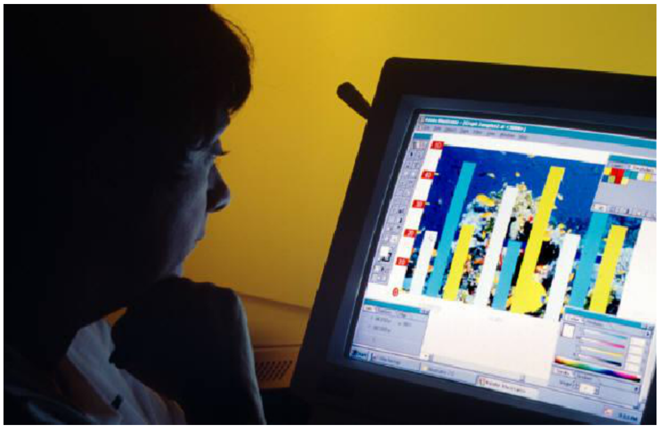
Even though most TV is still analog, two types of digital TV are now available.

In satellite TV, the video and sound are digitized and transmitted up to the satellite for retransmission to the earth receivers. The earth receivers convert the digital signals back into analog video and sound.

The second digital TV is high definition television (HDTV). HDTV is transmitted by local stations just as current analog TV is. DACs in the receivers recreate the video and audio.

Common Applications for Data Conversion

Video monitors use DACs to convert the binary data from the computer into voltages that drive the red, green, and blue color guns in the cathode ray tube (CRT). The CRT then turns on the intensity of each red-green-blue (RGB) pixel or dot to create the desired color at the desired location on the face of the tube.



Common Applications for Data Conversion

In industrial applications, the analog signal from a sensor, such as a temperature transducer, is digitized and transmitted to a controller. The temperature is measured and displayed. In some cases, it is used as a feedback signal for a closed-loop control system.

Digital signals from a computer can control the position of a robotic arm or other motion controlled device by sending digital data to a DAC. That signal is then used to drive a motor for the positioning.

DACs are also widely used in programmable power supplies and signal generators in automatic test systems.

Test your knowledge

Data Conversion Knowledge Probe 1

Data Conversion Fundamentals

Click on Course Materials at the top of the page.

Then choose **Knowledge Probe 1**.