COMP 202. Introduction to Electronics

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Analogue vs Digital Systems

We live in an *analogue* world. There are an *infinite* amount of colours to paint an object (even if the difference is indiscernible to our eye), there are an infinite number of tones we can hear, and there are an infinite number of smells we can smell.

The common theme among all of these analogue signals is their infinite possibilities.

Digital signals and objects deal in the realm of the *discrete* or finite, meaning there is a limited set of values they can be. That could mean just two total possible values, 255, 4,294,967,296, or anything as long as it's not ∞ (infinity).

Analogue & Digital

Real-world objects can display data, gather inputs by either analogue or digital means. (From left to right): Clocks, multimeters, and joysticks can all take either form (analogue above, digital below).

Analogue vs Digital Systems

Analogue & Digital

Working with electronics means dealing with both analogue and digital signals, inputs and outputs.

All electronics projects have to interact with the real, analogue world in some way, but most of our microprocessors, computers, and logic units are purely digital components.

These two types of signals are like different electronic languages; some electronics components are bi-lingual, others can only understand and speak one of the two.

What are signals?

By signals we mean time-varying “quantities” which convey some sort of information. In electrical engineering the quantity that’s time-varying is usually voltage (if not that, then usually current).

So think of a signal as a voltage that’s changing over time.

Signals are passed between devices in order to send and receive information, which might be video, audio, or some sort of encoded data.

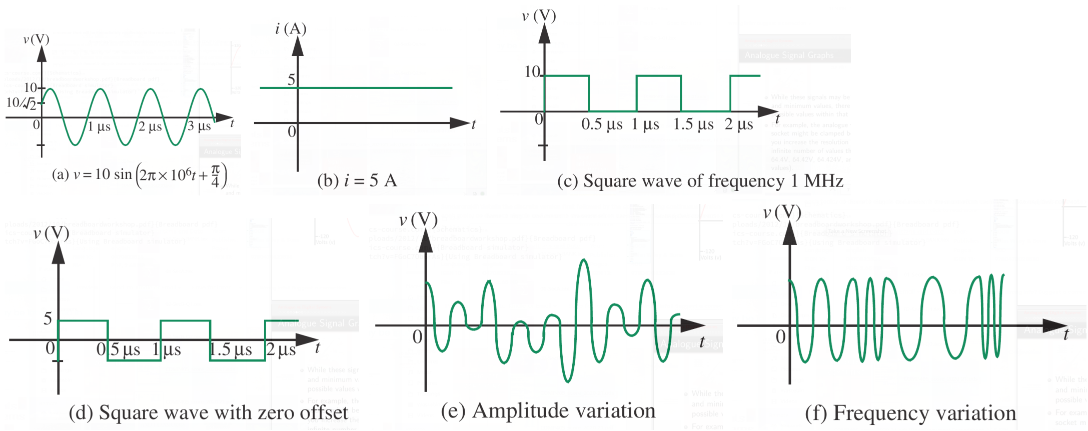
Usually the signals are transmitted through wires, but they could also pass through the air via radio frequency (RF) waves. Audio signals, for example might be transferred between your computer’s audio card and speakers, while data signals might be passed through the air between a tablet and a WiFi router.

Analogue Signal Graphs

Since a signal varies over time, it’s helpful to plot it on a graph where time is plotted on the horizontal, x-axis, and voltage on the vertical, y-axis.

Looking at a graph of a signal is usually the easiest way to identify if it’s analogue or digital; a time-versus-voltage graph of an analog signal should be smooth and continuous.

Analogue Signal Graphs



Several examples of analog signals: (a) a 1-MHz sinusoidal signal with amplitude 10 V and a phase offset of $\pi/4$; (b) a 5-A DC signal; (c) a 1-MHz square wave signal with a 5-V offset; (d) a 1-MHz square wave signal with zero offset; (e) a signal carrying information in its amplitude; (f) a signal carrying information in its frequency.

Analogue Signal Graphs

While these signals may be limited to a range of maximum and minimum values, there are still an infinite number of possible values within that range.

For example, the analogue voltage coming out of your wall socket might be clamped between -120V and +120V, but, as you increase the resolution more and more, you discover an infinite number of values that the signal can actually be (like 64.4V, 64.42V, 64.424V, and infinite, increasingly precise values).

Example Analog Signals

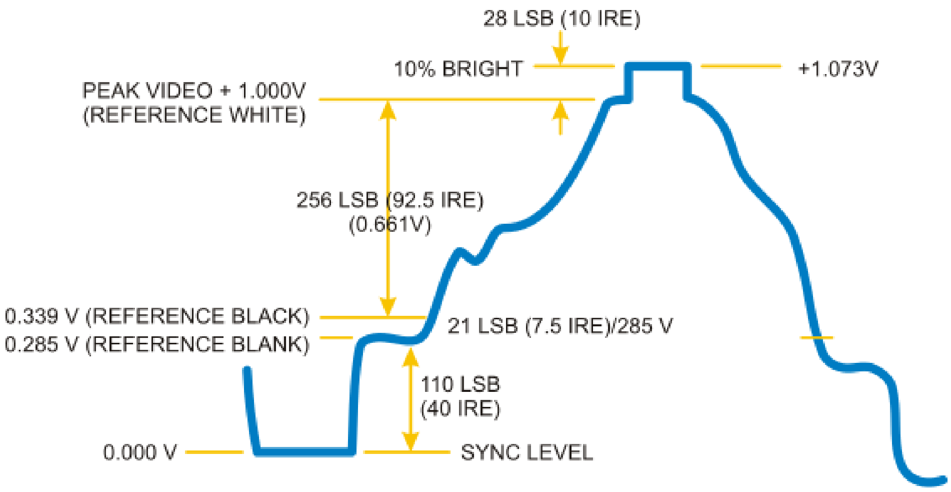
Video and audio transmissions are often transferred or recorded using analogue signals. The composite video coming out of an old RCA jack, for example, is a coded analogue signal usually ranging between 0 and 1.073V.

Tiny changes in the signal have a huge effect on the colour or location of the video.

Pure audio signals are also analogue. The signal that comes out of a microphone is full of analogue frequencies and harmonics, which combine to make beautiful music.

Analogue vs Digital Systems

Example Analogue Signals



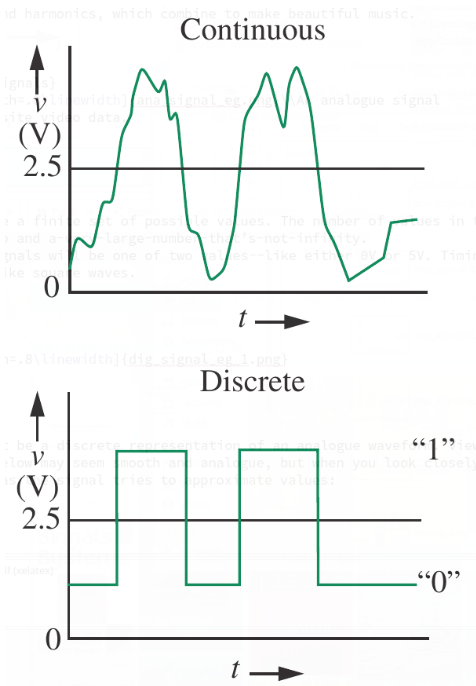
An analogue signal representing one line of composite video data.

Digital Signals

Digital signals must have a finite set of possible values. The number of values in the set can be anywhere between two and a-very-large-number-that's-not-infinity.

Most commonly digital signals will be one of two values–like either 0V or 5V. Timing graphs of these signals look like square waves.

Digital Signals



Here, we discretize voltage into a finite number of information levels, for example, the two levels named "0" and "1." Under this quantization, if a voltage is observed to be below 2.5 V we interpret its value as representing the information level "0." If its value is above 2.5 V, we interpret it as representing the information level "1." Correspondingly, to produce the information level "0," we use any voltage less than 2.5 V. For example, we might use 1.25 V. Correspondingly, to produce the information level "1," we might use the voltage 3.75 V.

Digital Systems

Discrete signals offer better noise immunity than analog signals, but they do so at the expense of precision.

If the noise that corrupts a discrete signal does not move its physical value past a discretization threshold, then the noise will be ignored.

For example, suppose the information level “0” in Figure above is represented by a 1.25-V signal, and the information level “1” is represented by a 3.75-V signal.

Provided the voltage does not rise above 2.5 V for “0,” or does not fall below 2.5 V for a “1,” it will be interpreted correctly.

Thus, this discrete signal representation is immune to ±1.25-V noise. Notice, however, the loss in precision our coarse two-level representation is unable to distinguish between small changes in the voltage.

For applications that care only about whether a signal is above or below some threshold, the loss in precision is of no consequence, and a two-level representation is sufficient.

However, for other applications that care about small changes in a signal, the basic two-level representation of a signal must be extended.

Briefly, to recover some precision while retaining noise immunity, digital systems quantize signals into a large number of levels for example, 256 and code these levels into a few binary digits 8, in our example, where each binary digit can be represented as a two-level voltage on a single wire.

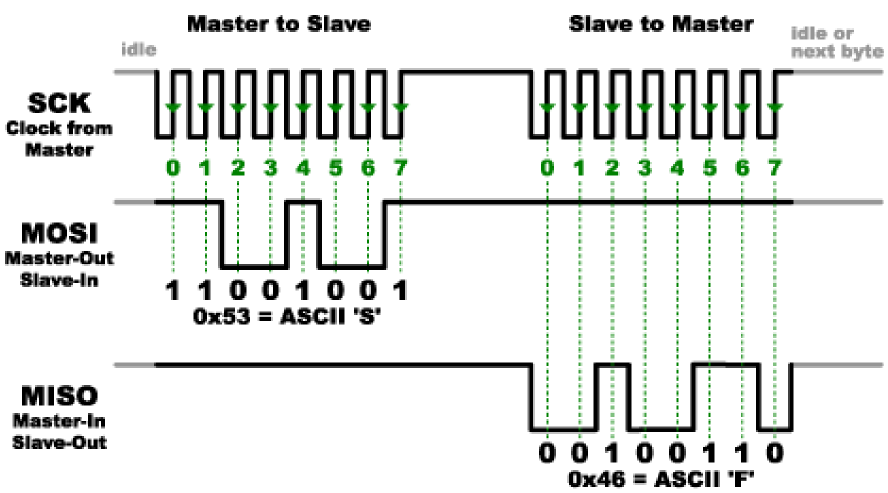
This method converts an analog signal on a single wire into a binary encoded signal on several wires, where each wire carries a voltage that can vary between two levels.

Example Digital Signals

Not all audio and video signals are analogue. Standardized signals like HDMI for video (and audio) and MIDI, I^2S, or AC'97 for audio are all digitally transmitted.

Most communication between integrated circuits is digital. Interfaces like serial, I^2C, and SPI all transmit data via a coded sequence of square waves.

Example Digital Signals



Serial peripheral interface (SPI) uses many digital signals to transmit data between devices.

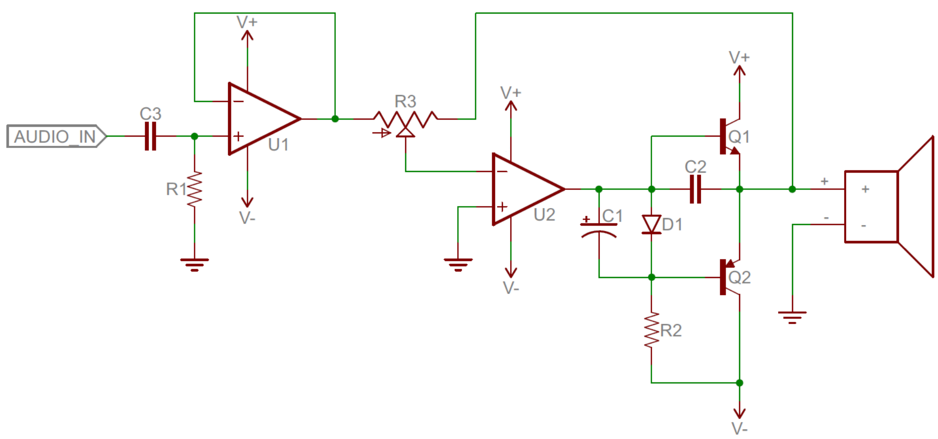
Analogue Electronics

Most of the fundamental electronic components – resistors, capacitors, inductors, diodes, transistors, and operational amplifiers – are all inherently analogue.

Circuits built with a combination of solely these components are usually analogue.

Analogue vs Digital Systems

Analogue Electronics



Analog circuits are usually complex combinations of op amps, resistors, caps, and other foundational electronic components. This is an example of a class B analogue audio amplifier.

Analogue Electronics

Analogue circuits can be very elegant designs with many components, or they can be very simple, like two resistors combining to make a voltage divider.

In general, though, analogue circuits are much more difficult to design than those which accomplish the same task digitally. It takes a special kind of analogue circuit wizard to design an analogue radio receiver, or an analogue battery charger; digital components exist to make those designs much simpler.

Analogue circuits are usually much more susceptible to noise (small, undesired variations in voltage). Small changes in the voltage level of an analogue signal may produce significant errors when being processed.

Digital Electronics

Digital circuits operate using digital, discrete signals. These circuits are usually made of a combination of transistors and logic gates and, at higher levels, micro-controllers or other computing chips.

Most processors, whether they're big beefy processors in your computer, or tiny little micro-controllers, operate in the digital realm.

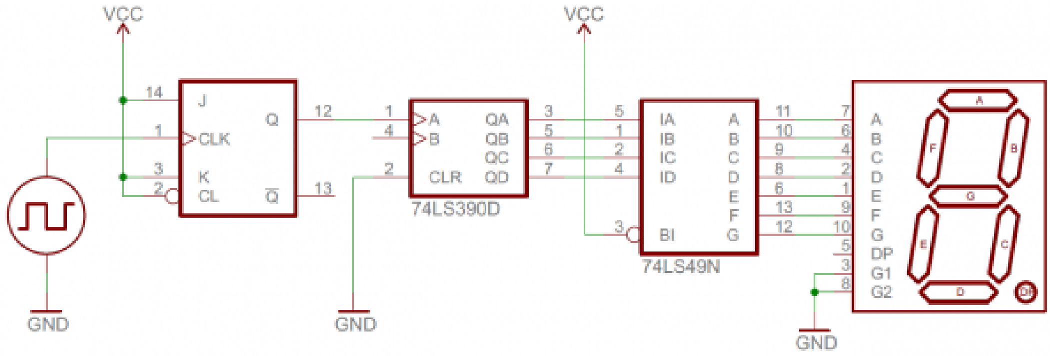
Digital circuits usually use a binary scheme for digital signaling. These systems assign two different voltages as two different logic levels–a high voltage (usually 5V, 3.3V, or 1.8V) represents one value and a low voltage (usually 0V) represents the other.

Digital Electronics

Although digital circuits are generally easier to design, they do tend to be a bit more expensive than an equally tasked analogue circuit.

Analogue vs Digital Systems

Digital Electronics



Analog and Digital Combined

It's not rare to see a mixture of analogue and digital components in a circuit.

Although micro-controllers are usually digital beasts, they often have internal circuitry which enables them to interface with analogue circuitry (analogue-to-digital converters, pulse-width modulation, and digital-to-analogue converters.

An analogue-to-digital converter (ADC) allows a micro-controller to connect to an analogue sensor (like photocells or temperature sensors), to read in an analogue voltage. The less common digital-to-analogue converter allows a micro-controller to produce analogue voltages, which is handy when it needs to make sound.

Find out some more

(a) `https://electronicsclub.info/analogue.htm`

(b) More on the differences between analogue and digital signals: `https://www.youtube.com/watch?v=WxJKXGugfh8`

(c) Watch some of the differences between analogue and digital music: `https://www.youtube.com/watch?v=lzRvSWPZQYk`