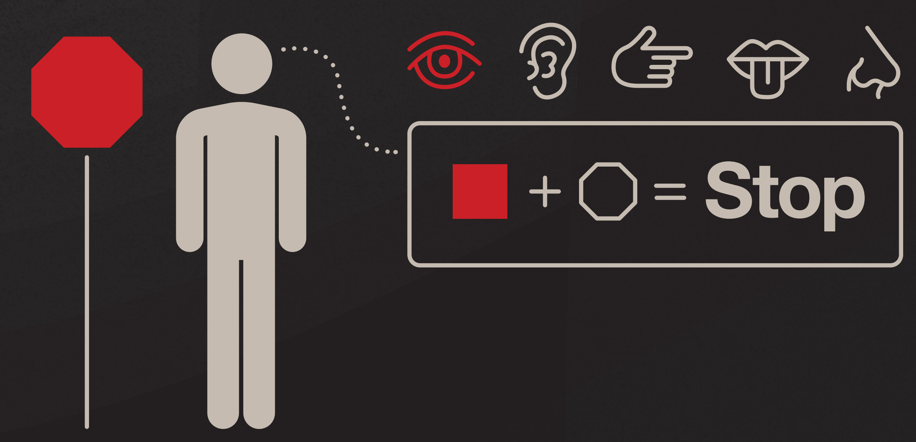
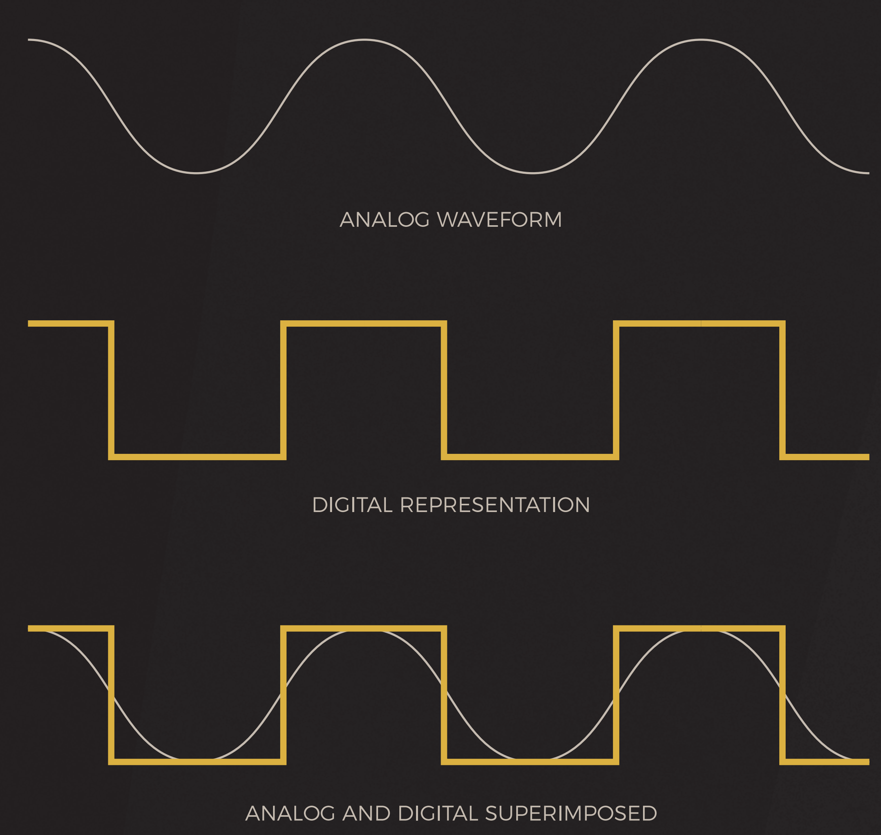
Analog and Digital Signals

HUMAN BEINGS are programmed to perceive an analog world. Our biological sensors record a constant, complex barrage that our brains combine and convert into understandable and useful information.

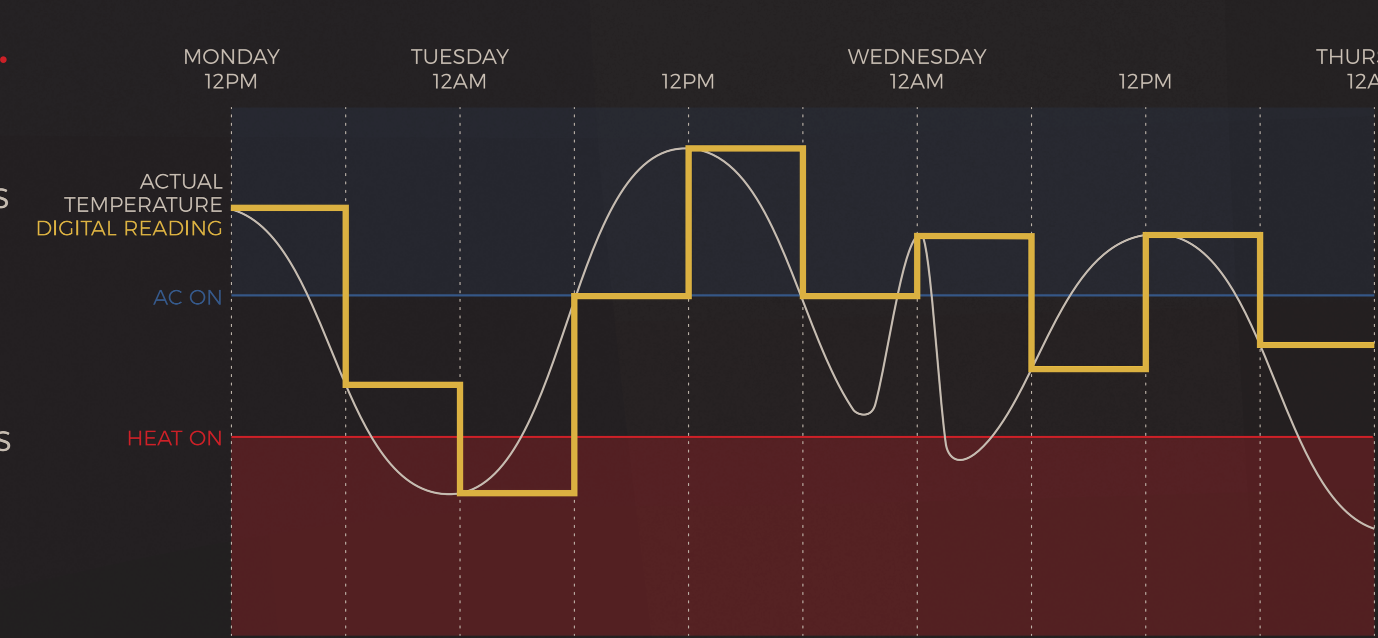


AS TECHNOLOGY HAS EVOLVED, we've created ways to interact with the world that makes our lives a bit easier. First, we created systems that respond to the analog world in real time, making mechanical devices and circuitry that effectively balance a stimulus with a response - like the float in your toilet tank that keeps it full, or a thermostat that uses two dissimilar metals with different expansion rates to give you responses over a range of temperatures. With the advent of the digital age, we've had to find ways of importing that analog information into our digital control systems. This is the process of digitization.



TO DIGITIZE AN ANALOG SIGNAL, we take a number of discrete measurements (samples) at regular intervals of time and store their values. Once the signal is in digital form, we can analyze its behavior and determine an appropriate response. The advantage of this over an analog system is substantial, because we can use software to very easily do our data manipulation and set any number of conditional thresholds and responses, rather than developing a complicated and often finicky electronic circuit to accomplish the same. Doing complicated math in software is a walk in the park compared to trying to reproduce similar results in circuitry, since precision component values can be expensive and inaccurate.

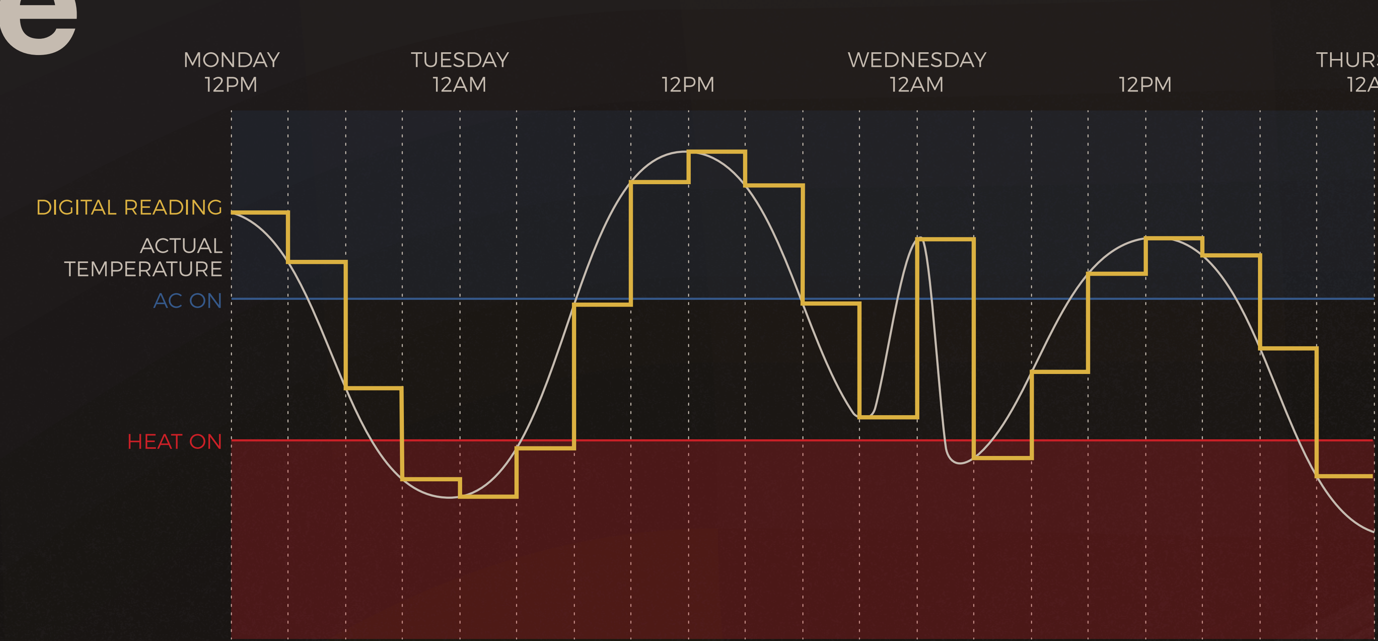
DIGITAL SYSTEMS ARE NOT WITHOUT SHORTCOMINGS. Getting a good digital representation of the original signal is paramount. Analyzing something like the temperature in a room and responding with AC or heat is a relatively simple endeavor because the signal changes so slowly. But higher-speed signals can be much more complicated to accurately replicate – there is inherent inaccuracy in our measurements. While we can determine a very precise time at which a measurement is taken, we don't know for certain what happened between samples. More than that, our measurements of magnitude also take on discrete values in digital form, values in between which we can't see.



IN THIS EXAMPLE, the sensor is taking heat readings every six hours. We see that while the digital readings generally follow the curve of the actual temperature, it doesn't always get it quite right and sometimes misses important details, like the unexpected spike in heat on Wednesday morning.

The Nyquist Rate

TO COMBAT THE ISSUE of what happens between samples, we take more samples so that there's less time between. In fact, it turns out that you have to take (at least) twice as many samples per second as the highest frequency of interest. This is known as the Nyquist rate, named for Harry Nyquist. For example, if you're trying to sample an FM radio signal centered at 97.3MHz, you would need to sample twice that, plus the bandwidth of the modulated signal, or around 195.4MHz.



HERE WE'VE TAKEN THE SAME TEMPERATURE DATA, but doubled the sample rate of the digital sensor, resulting in much more accurate heating and cooling and hopefully, a more comfortable home.

Magnitude Granularity

TO COMBAT THE ISSUE of magnitude granularity, our measurements are represented by more bits. For example, if we sample a voltage between 0 and 5 volts and represent it with a 10-bit number, our 5-volt range is split into 2^10 (1,024) chunks. That makes the variance between sample levels 5V/1024 = 4.88mV. If we increase our number to 12 bits, our 5V range is split into 2^12 (4,096) chunks. That brings our variance between sample levels down to 5V/4096 = 1.22mV.

Learn More

KEEP GOING! If you want to learn more about analog and digital signals and how to use them appropriately in your next project, you can find plenty of tutorials and guides at **learn.sparkfun.com.**

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