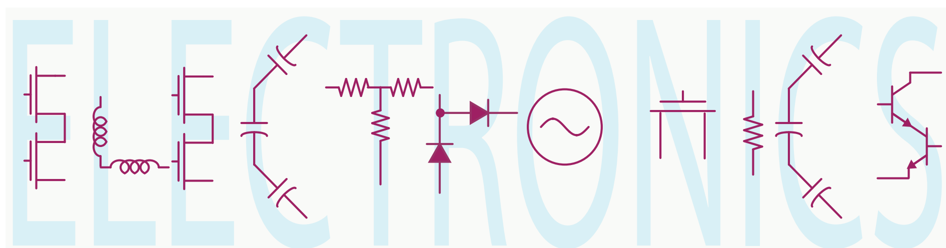
EE 42/100
Lecture 21: Digital Gates and Combinatorial Logic



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Digital versus Analog

- Real signals are continuous (at least we perceive them that way) whereas binary signals can only take on two values.
- For instance the current temperature in this room is a certain number of degrees and the resolution of this number is in principle infinite (noise limited).
- But for many applications, the precise value is not important. A finite representation (certain number of significant figures) is all that we need. We may therefore sample the signal periodically (not continuously) and also round off the actual amplitude of the signal. Note that we are making two approximations: the discrete time sampling of the signal and the discretization process.
- Intuitively, as long as we sample the signal faster than the rate at which it changes (can be made precise using Nyquist's Sampling Theorem), then no information is lost.

→ COMPUTERS HAVE FINITE PRECISION

→ "TRUNCATE THE DECIMAL"

→ FINITE RANGE

Quantization Noise

- On the other hand, the quantization of the signal introduces round-off errors in our signal. If we subtract out the ideal signal $s(t)$ from the quantized signal $\hat{s}(t)$, the difference is the error signal, which varies randomly from sample to sample.

$$n(t) = s(t) - \hat{s}(t)$$

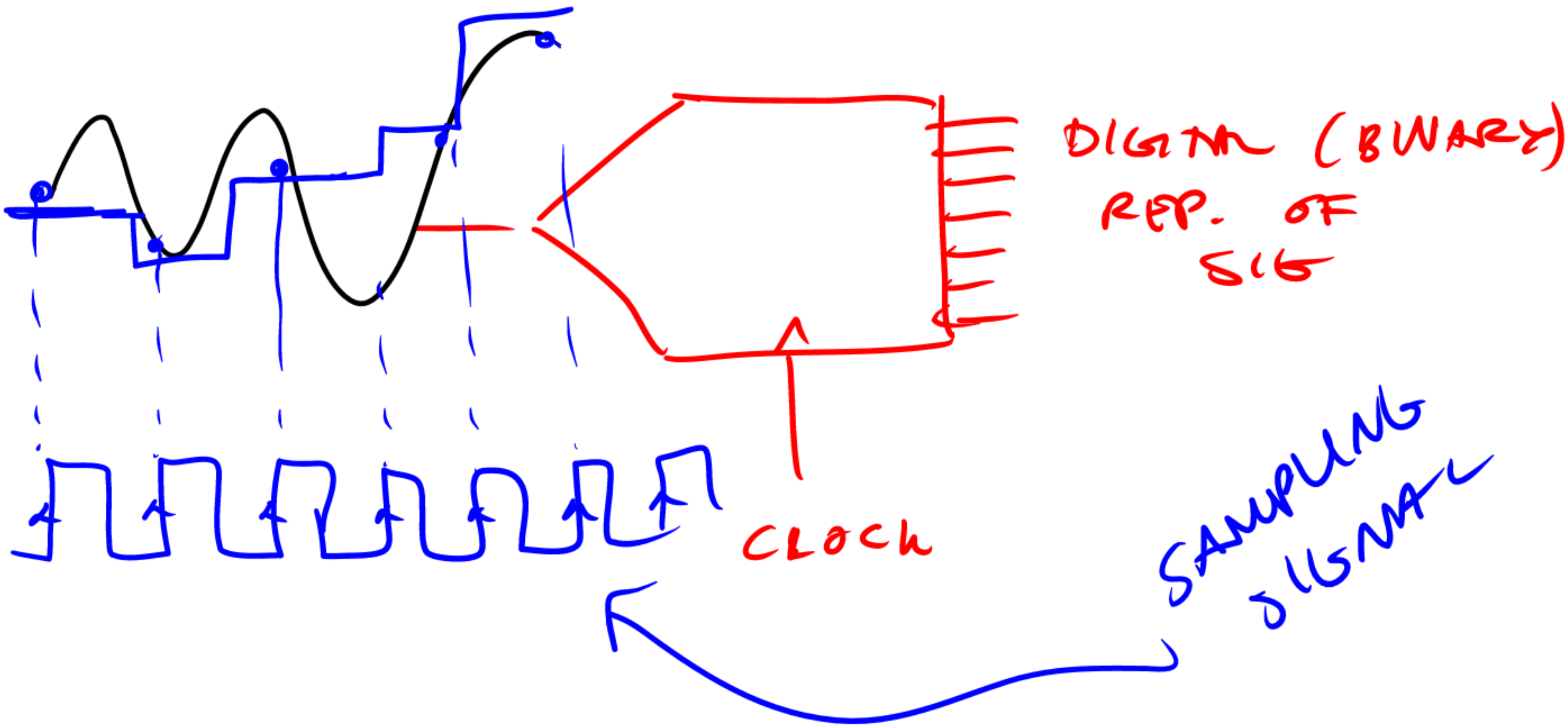
- We can therefore think of the process as introducing "quantization noise" in the signal.

$$\hat{s}(t) = s(t) - n(t)$$

- In other words, if we are insensitive to changes of the signal smaller than the quantization noise, then the approximation is okay.

Analog-to-Digital Converter

- The important specifications for an ADC are the sampling rate (clock rate) of the ADC and its resolution (number of bits).
- Analog signals need to be sampled at a rate of twice the signal bandwidth (audio bandwidth is roughly 5 kHz).
- The resolution determines the smallest discernible signal since the full-scale input voltage (say 5V) is divided by 2^N where N is the number of bits. Any signal smaller than this level is lost in the “quantization noise” (round-off error).



Binary Numbers

- Binary numbers can only take on two values $\{0, 1\}$. To specify a bigger number, you have to use more digits. For instance:

$$1010_b = (1)2^3 + (0)2^2 + (1)2^1 + 0(2^0) = 8 + 2 = 10$$

- Some aliens with only two fingers may naturally use binary numbers but we use them because our computers can only store two states (note: digit means finger).
- To convert a decimal number into binary, you can repeatedly divide by 2 and take the remainder as the next digit.
- Example: 50 in binary is: $50/2 = 25r0, 25/2 = 12r1, 12/2 = 6r0, 6/2 = 3r0, 3/2 = 1, r1, 1/2 = 0r1$. This implies the number is given by 110010_b (read it backwards). Verify that $2^4 + 2^1 = 8 + 4 = 12$. Or

$$32 + 16 + 2 = 2^5 + 2^4 + 2^1 = 110010_b$$

Binary Signals

- Binary signals are designed to only take on two values, say $\{0V, 5V\}$ to represent $\{0, 1\}$ (positive or negative logic possible).
- As signals propagate in wires, inevitably noise, distortion, and cross-talk occurs, which corrupts the signal. An analog signal is corrupted directly whereas a digital signal is only corrupted if the noise exceeds the noise margin of the circuit.
- Digital signals are therefore more robust and can be easily regenerated whereas analog signals get more noisy as we process them.