Latin-American alliance for capacity building in advanced physics

LA-CoNGA physics

Módulo de Instrumentación

Introducción a los Sistemas de Medida

Dennis Cazar Ramírez

Universidad San Francisco de Quito USFQ

25 - enero - 2021

Latin American alliance for Capacity buildiNG in Advanced physics

LA-CoNGA physics

Cofinanciado por el programa Erasmus+ de la Unión Europea

Contents

Introduction to Measuring systems

- Electric Signals
- Noise
- Fourier Analysis

DC vs AC signals

- Direct Current or DC signals are voltage and current that does not change in time
- DC voltages are generated by batteries, DC voltage sources
- DC voltages have the same polarity

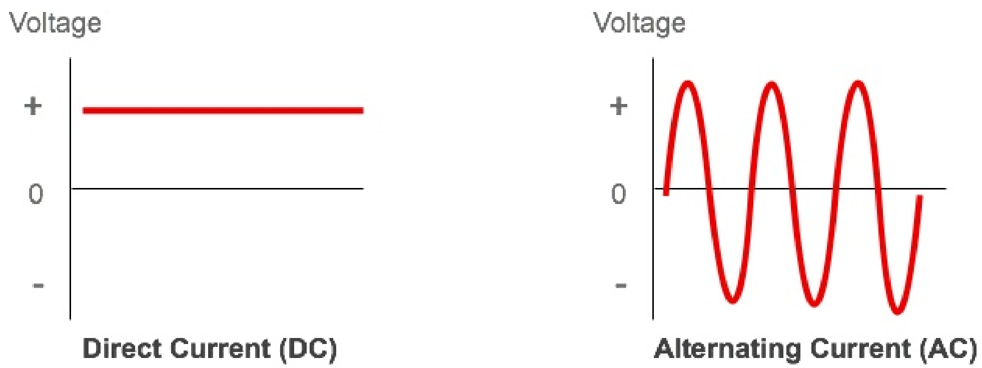


Figure 1: Voltage versus time representation of an DC and AC voltage

- Alternating current or AC signals are voltages and currents that vary in time
- AC signals have frequency, period , phase, etc.

AC signals definitions

- Sinusoidal signals. This is probably the most fundamental signal in electronics since, as we will see later, any signal can be constructed from sinusoidal signals
- Sinusoidal voltages can be written

$$V = Asin(2\pi ft + \phi) = Asin(\omega t) \quad (1)$$

- where A is the amplitude, f is the frequency in cycles/second or hertz (abbreviated Hz), ϕ is the phase, and ω is the angular frequency (in radians/second).
- The repetition time is called the period T of the signal, and this is related to the frequency of the signal by $T = \frac{1}{f}$

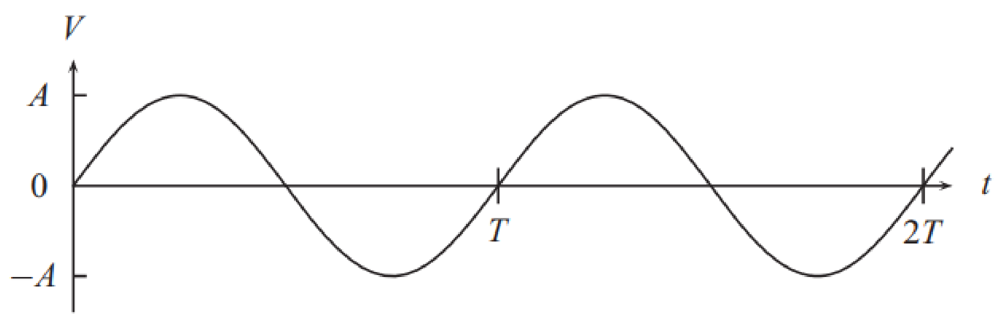


Figure 2: Voltage versus time representation of an DC and AC voltage

AC signals definitions

- There are several ways to specify the amplitude of a sinusoidal signal that are in common use. These include the following.
  - The peak amplitude A or A_p.
  - The peak-to-peak amplitude $A_{pp} = 2A$.
  - The "root mean square" or rms amplitude $A_{rms} = \dfrac{A}{\sqrt{2}}$
- RMS value is useful for power calculations involving sinusoidal waves. For example, suppose we want the power dissipated in a resistor given the sinusoidally varying voltage across it.

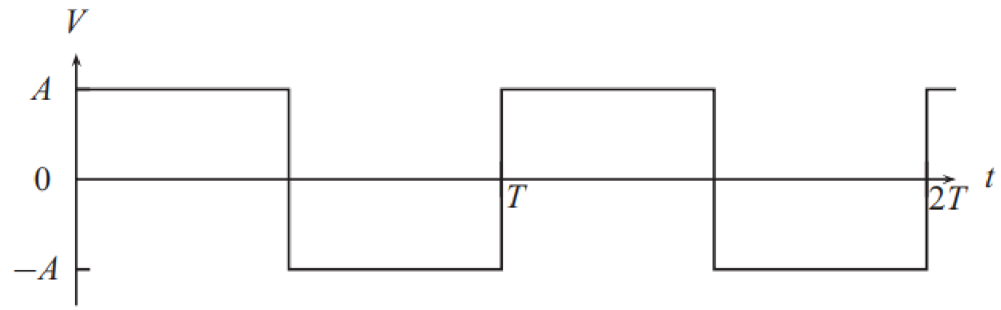
$$P = \frac{1}{T}\int_0^T \frac{V^2}{R} = \frac{A_{rms}^2}{R} \tag{2}$$

- Decibels (abbreviated dB) are used to compare the amplitude of two signals, say A_1 and A_2:

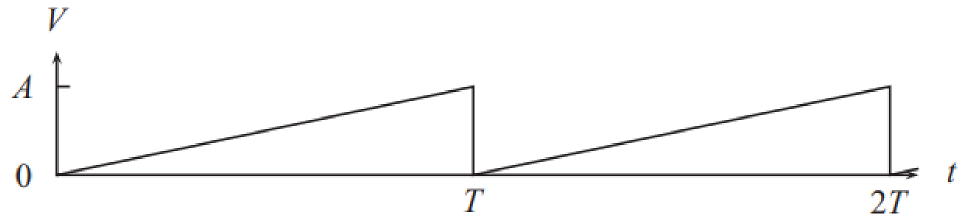
$$dB = 20\, log_{10}\frac{A_2}{A_1} = 10\, log_{10}\left(\frac{A_2}{A_1}\right)^2 = 10\, log_{10}\frac{P_2}{P_1} \tag{3}$$

Other signals

- **Square wave:** Specified by an amplitude and a frequency (or period).



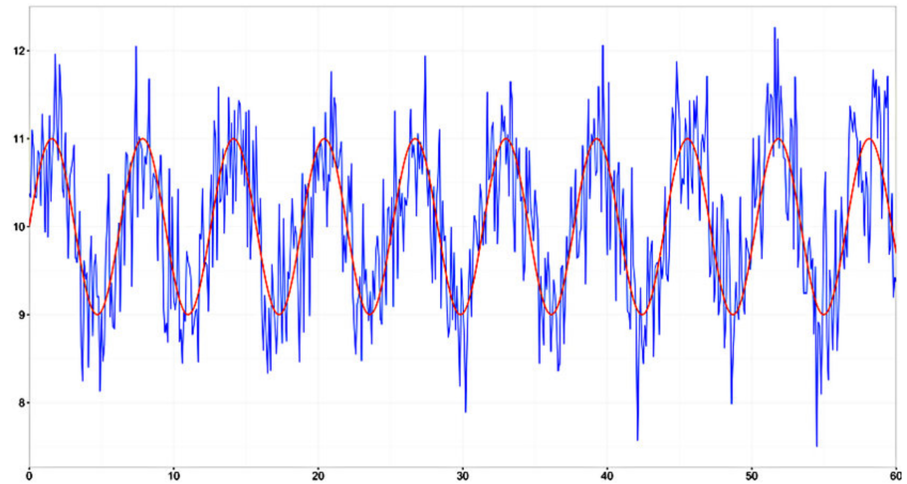
- **Sawtooth wave:** Specified by an amplitude and a frequency (or period).



Noise

- **Noise.** These are random signals of thermal origin or simply unwanted signals coupled into the circuit.

- Electromagnetic noise is a ubiquitous and often significant factor in circuit design, it is manifested by means of current and voltage variations.

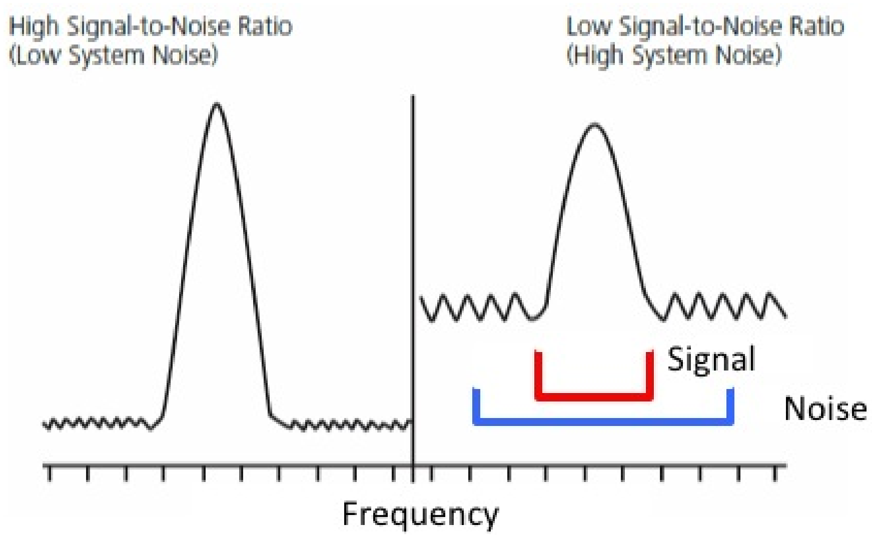


Types of noises

- **Thermal Noise:** This is a fundamental reality associated with resistance to the flow of electrons.
  - Unless we start designing circuits out of superconductors, we'll always have thermal noise, because everything has at least a little bit of resistance.
  - Thermal noise is manifested as random voltage variations; it is related to temperature, resistance, and bandwidth.
  - Higher temperature and higher resistance lead to higher noise amplitude.
  - Bandwidth here refers to the range of frequencies that are relevant to the circuit. If you include more frequencies in your analysis, you'll see more thermal noise.
  - Thermal noise is random in nature, we can assume that it has a normal distribution
- **Shot Noise:** Electrons don't actually "flow" through a conductor. They sort of bump along, with potential energy accumulating and then being converted into kinetic energy each time the electron has to cross a barrier.
  - These random variations in electron motion lead to corresponding random variations in current. In other words, noise
  - Shot noise is more prominent in semiconductors than in conductors because semiconductors have more barriers.
  - Higher current leads to more shot noise, and so does wider bandwidth
- **$1/f$ or Flicker Noise:** is generated by most electronic components and decreases in amplitude as frequency increases.
  - The name "1/f" (i.e., "inversely related to frequency") reminds us that the relationship between amplitude and frequency is a prominent characteristic of flicker noise.

Signal to Noise ratio

- **Signal to Noise Ratio or SNR** is defined as the ratio of signal power to the noise power,
- SNR is often expressed in decibels.
- A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise.
- **Dynamic range:** Dynamic range measures the ratio between the strongest un-distorted signal on a channel and the minimum discernible signal, which for most purposes is the noise level.



- Let $f(t)$ be any real, periodic function with period T such that $f(t) = f(t+T)$ for any t. Then there exist complex constants $\hat{c}_n$ such that

$$f(t) = \sum_{n=-\inf}^{\inf} \hat{c}_n e^{j\omega_n t} \tag{4}$$

- where $\omega_n = \frac{2\pi n}{T}$
- and the constants are given by

$$\hat{c}_n = \frac{1}{T}\int_{t'}^{t'+T} f(t) e^{j\omega_n t} dt \tag{5}$$

- Terms in eq (4) are called *Harmonics*
- The Fourier's theorem states that every nonsinusoidal periodic wave can be decomposed as the sum of sine waves through the application of the Fourier series.
- In other words we can represent any signal with their "frequency components"

Time vs Frequency domain

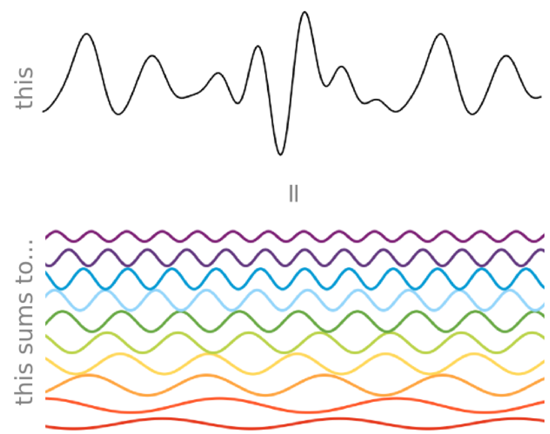


Figure 3: A typical electronic signal is a sum of sinusoidal waves

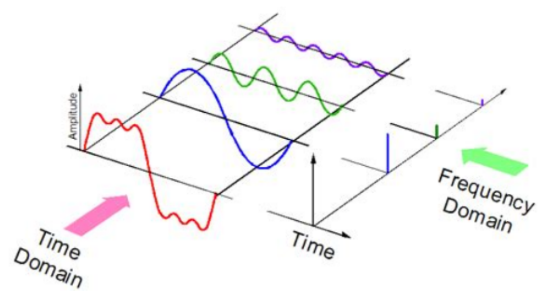


Figure 4: Time Domain vs Frequency domain time representation of a square signal