Signal Energy vs. Signal Power*

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Abstract

Defines energy and power as ways to measure a signal.

The idea of the "size" of a signal is crucial to many applications. It is nice to know how much electricity can be used in a defibrillator without ill effects, for instance. It is also nice to know if the signal driving a set of headpones is enough to create a sound. While both of these examples deal with electric signals, they are clearly very different signals with very different tolerances. For this reason, it is convenient to quantify this idea of "size". This leads to the ideas of signal energy and signal power.

1 Signal Energy

Since we often think of signal as a function of varying amplitude through time, it seems to reason that a good measurement of the strength of a signal would be the area under the curve. However, this area may have a negative part. This negative part does not have less strength than a positive signal of the same size (reversing your grip on the paper clip in the socket is not going to make you any more lively). This suggests either squaring the signal or taking its absolute value, then finding the area under that curve. It turns out that what we call the **energy** of a signal is the area under the squared signal.

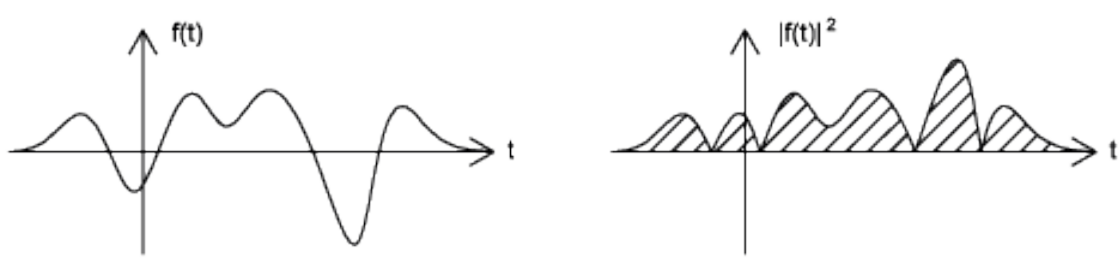

Figure 1: The energy of this signal is the shaded region.

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$$E_f = \int_{-\infty}^{\infty} (|f(t)|)^2 dt \tag{1}$$

2 Signal Power

Our definition of energy seems reasonable, and it is. However, what if the signal does not decay? In this case we have infinite energy for any such signal. Does this mean that a sixty hertz sine wave feeding into your headphones is as strong as the sixty hertz sine wave coming out of your outlet? Obviously not. This is what leads us to the idea of **signal power**.

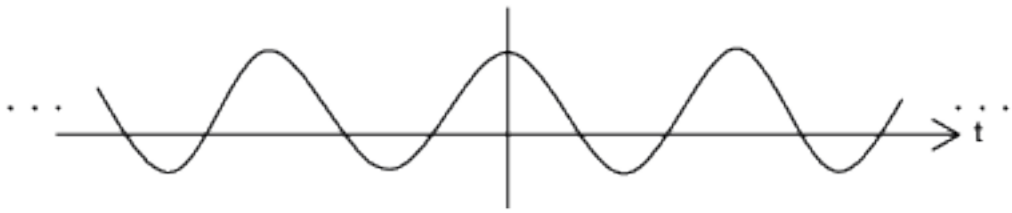

Figure 2: A simple, common signal with infinite energy.

Power is a time average of energy (energy per unit time). This is useful when the energy of the signal goes to infinity.

$$P_f = \underset{T\to\infty}{\text{limit}} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} (|f(t)|)^2 dt \tag{2}$$

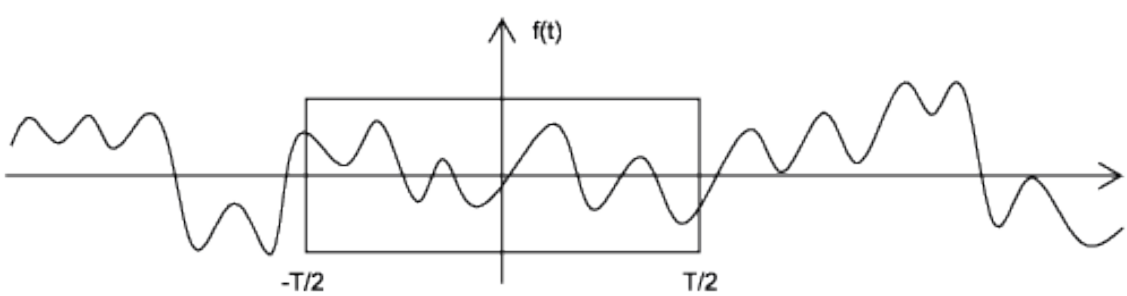

Figure 3: We compute the energy per a specific unit of time, then allow that time to go to infinity.

1. Compute $\frac{\text{Energy}}{T}$
2. Then look at $\underset{T\to\infty}{\text{limit}} \frac{\text{Energy}}{T}$

P_f is often called the mean-square value of f. $\sqrt{P_f}$ is then called the **root mean squared** (**RMS**) value of f.

3 Energy vs. Power

- "Energy signals" have finite energy.
- "Power signals" have finite and non-zero power.

Exercise 1 ***(Solution on p. 4.)***

Are all energy signals also power signals?

Exercise 2 ***(Solution on p. 4.)***

Are all power signals also energy signals?

Exercise 3 ***(Solution on p. 4.)***

Are **all** signals either energy or power signals?

Solutions to Exercises in this Module

Solution to Exercise (p. 3)
No. In fact, any signal with finite energy will have zero power.
Solution to Exercise (p. 3)
No, any signal with non-zero power will have infinite energy.
Solution to Exercise (p. 3)
No. Any infinite-duration, increasing-magnitude function will not be either. (eg $f(t) = t$ is neither)