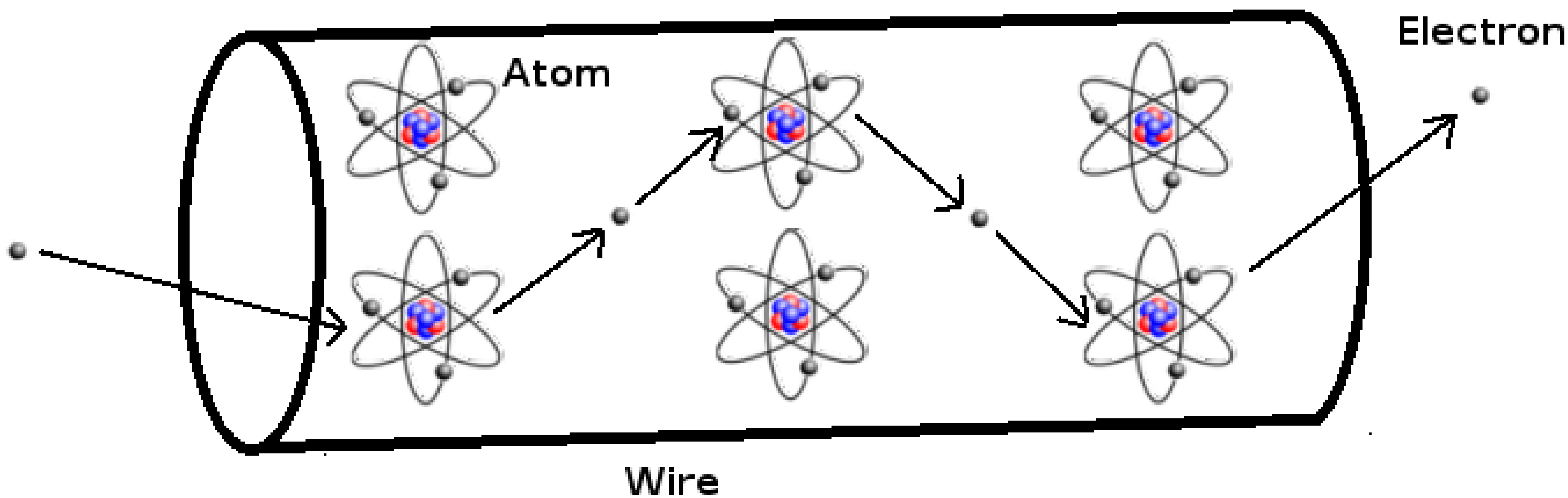
Data vs. Signal (cont.)

Flow of Electrons Through a Conductor …

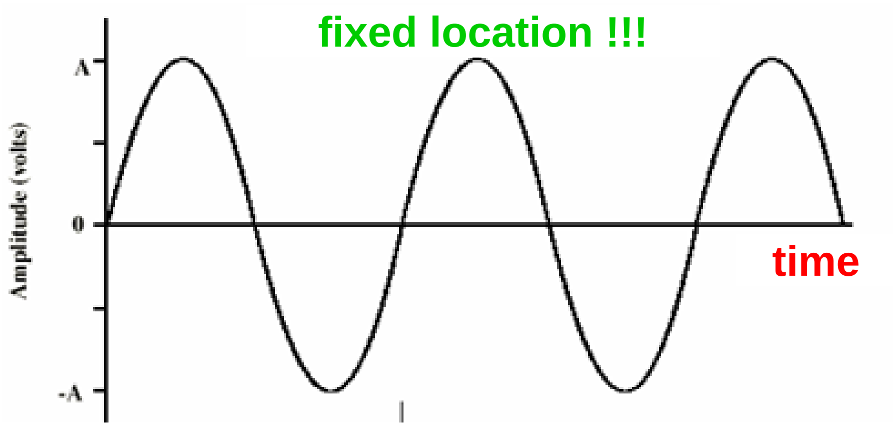


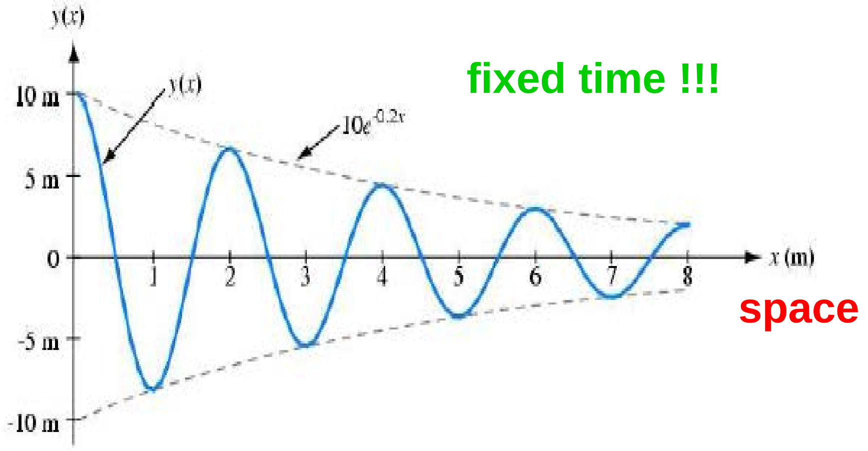
https://electronicspani.com/what-is-electric-current/

Signal Representation

Signal Representation – **typically in 2D space, as a function of <u>time</u>, <u>space</u> or frequency**

- **when horizontal axis is time, graph displays the value of a signal at <u>one particular point in space</u> as a function of time**
- **when horizontal axis is space, graph displays the value of a signal at <u>one particular point in time</u> as a function of space**





The time- and space- representation of a signal often resemble each other,
though the signal envelope in the space-representation is different (signal attenuates over distance).

- Data vs. Signal
- **Analog vs. Digital**
- Analog Signals
    - Simple Analog Signals
    - Composite Analog Signals
- Digital Signals

Analog vs. Digital

Analog vs. Digital Data

- **analog data** – representation variable takes on continuous values in some interval, e.g. **voice**, **temperature**, etc. recording/reading
- **digital data** – representation variable takes on discrete (a finite & countable number of) values in a given interval, e.g. **text**, **digitized images**, etc.

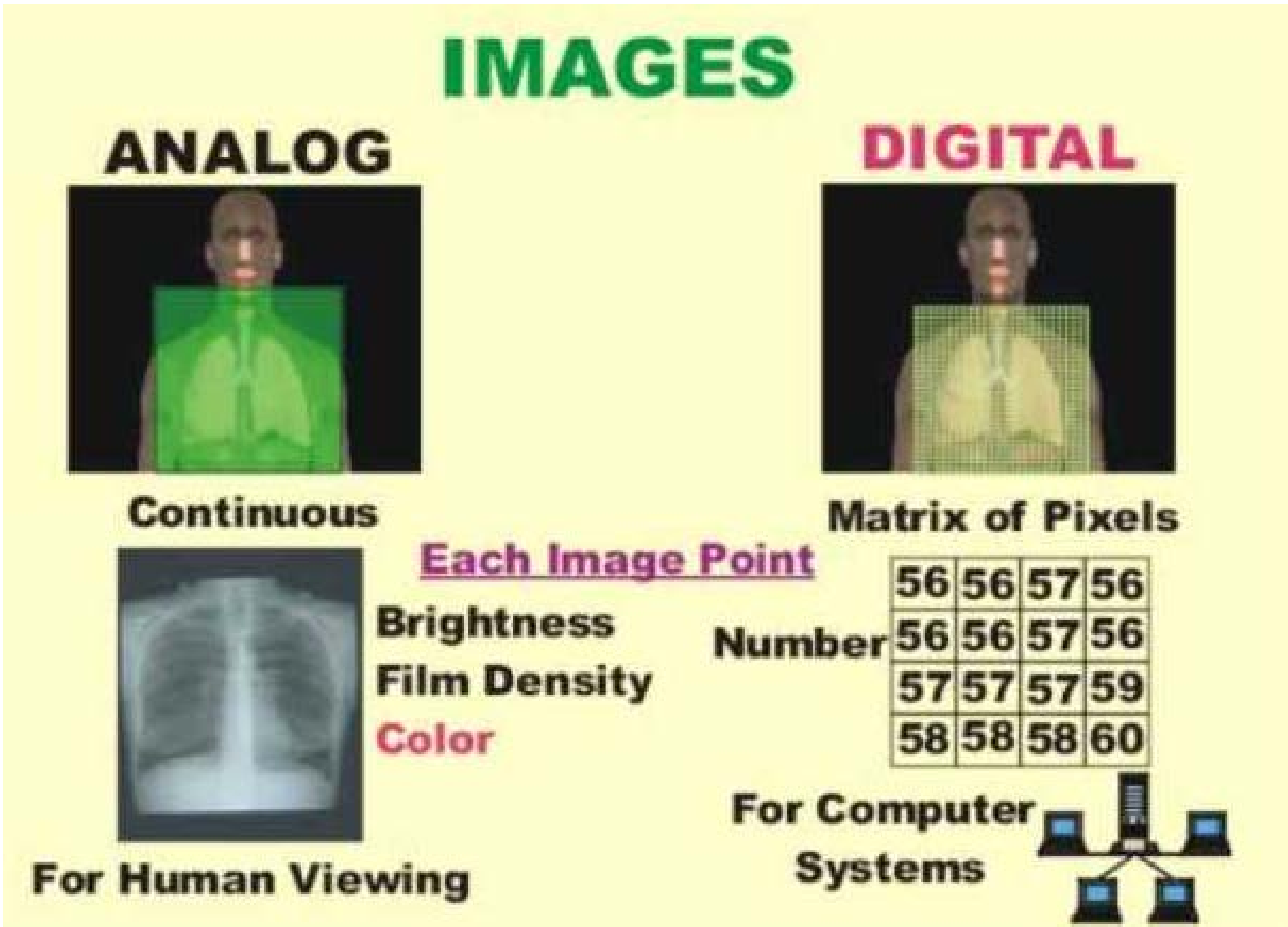
Analog vs. Digital Signal

- **analog signal** – signal that is continuous in time and can assume an infinite number of values in a given range (continuous in time and value)
- **discrete (digital) signal** – signal that is continuous in time and assumes only a limited number of values (maintains a constant level and then changes to another constant level)

Stallings, pp. 65 "This is an idealized definition. In fact, the transition from one voltage to another is not instantaneous, but there is a small transition period."

Analog vs. Digital (cont.)

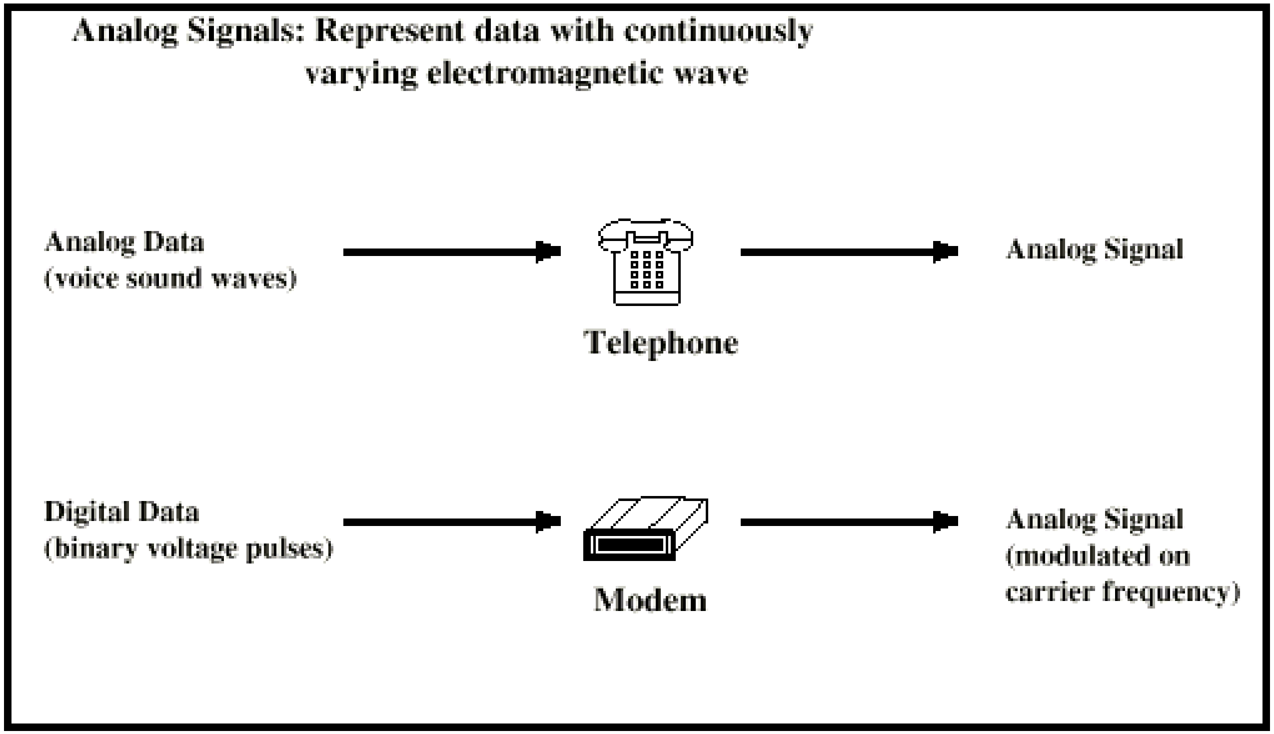
Analog vs. digital data …



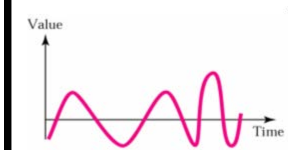
Analog vs. Digital (cont.)

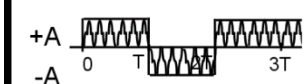
Both analog and digital data can be transmitted using either analog or digital signals.

DATA



SIGNAL





example: analog signaling of analog and digital data

... will talk more about this later ...

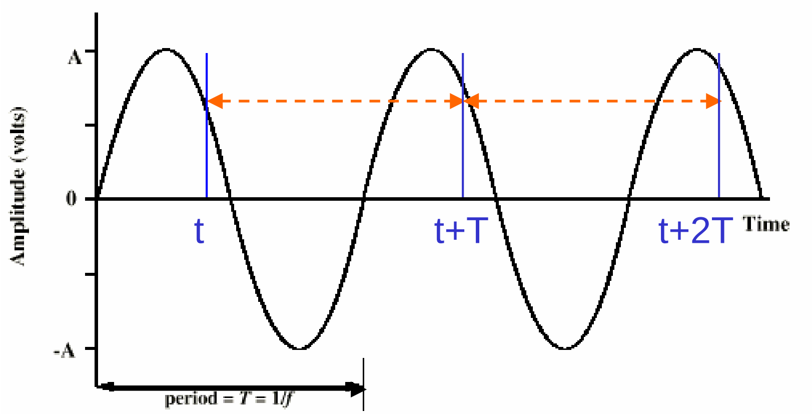
Periodic vs. Aperiodic Signals

- **periodic signal – completes a pattern within some measurable time frame, called a period (T), and then repeats that pattern over sub-sequent identical periods**

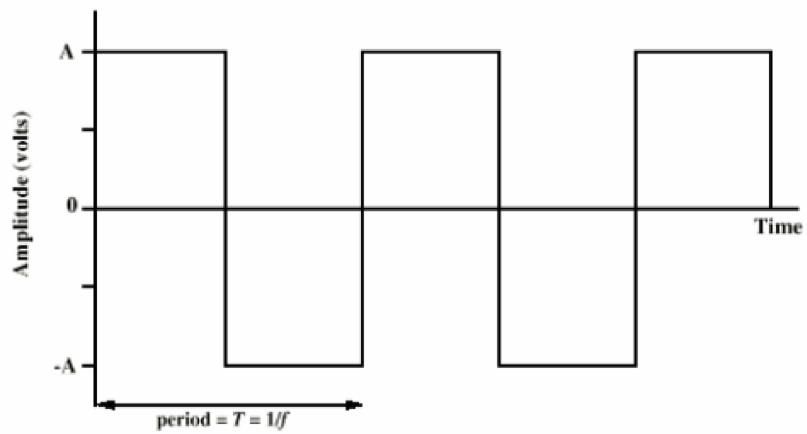
$$\exists T \in R \quad s.t. \quad s(t+T) = s(t), \ \forall t \in \langle -\infty, +\infty \rangle$$

  - **T - smallest value that satisfies the equation**
  - **T is (typically) expressed in seconds**

- **aperiodic signal – changes without exhibiting a pattern that repeats over time**



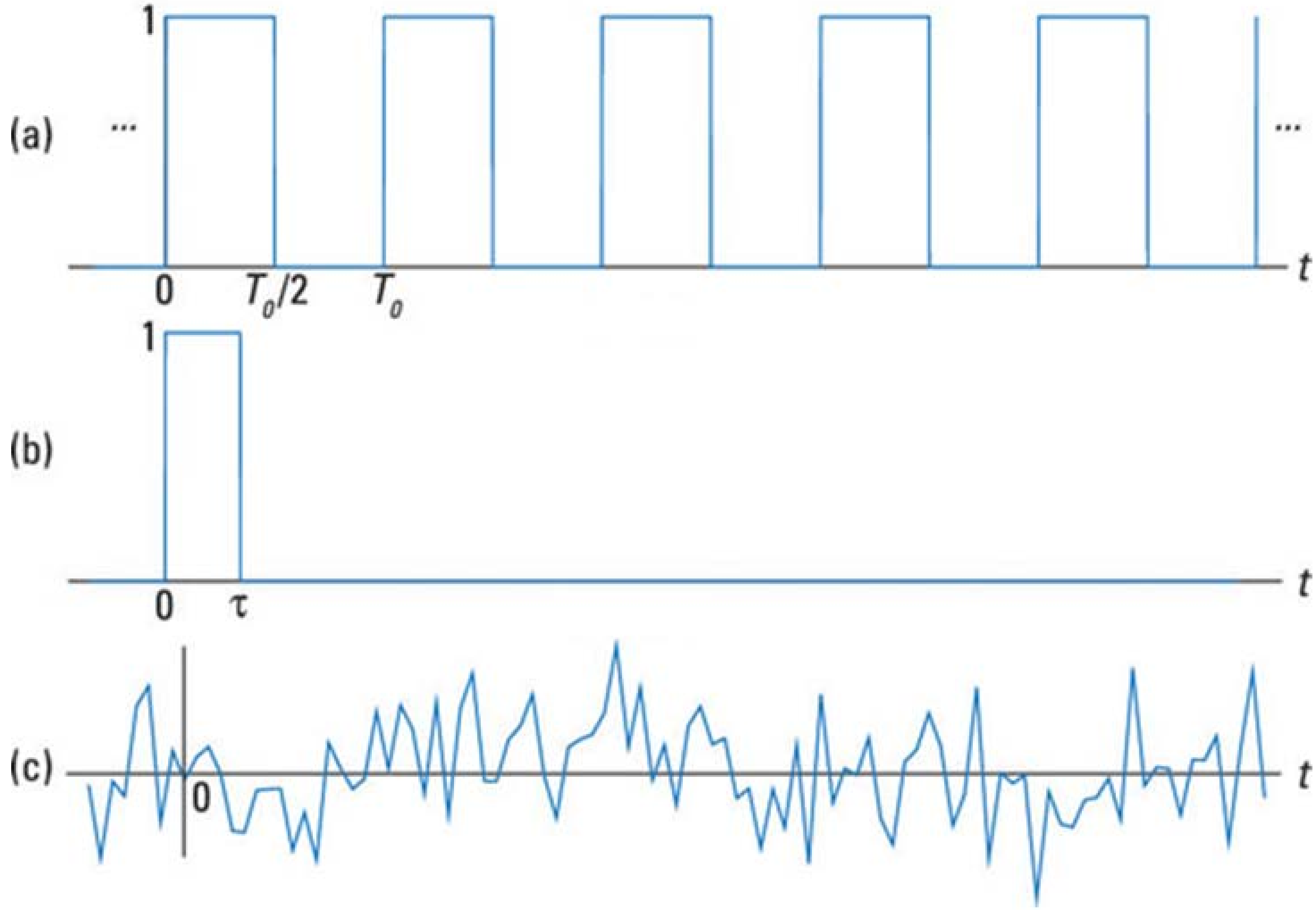
periodic analog signal



periodic digital signal

Analog vs. Digital (cont.)

Different types of signals (analog, digital, periodic, aperiodic, …)



periodic & digital

aperiodic & digital & **deterministic!**

aperiodic & analog & **random!**

- Data vs. Signal
- Analog vs. Digital
- **Analog Signals**
  - Simple Analog Signals
  - Composite Analog Signals
- Digital Signals

Analog Signals

Classification of Analog Signals

(1) Simple Analog Signal – cannot be decomposed into simpler signals

- **sinewave – most fundamental form of periodic analog signal – mathematically described with 3 parameters**

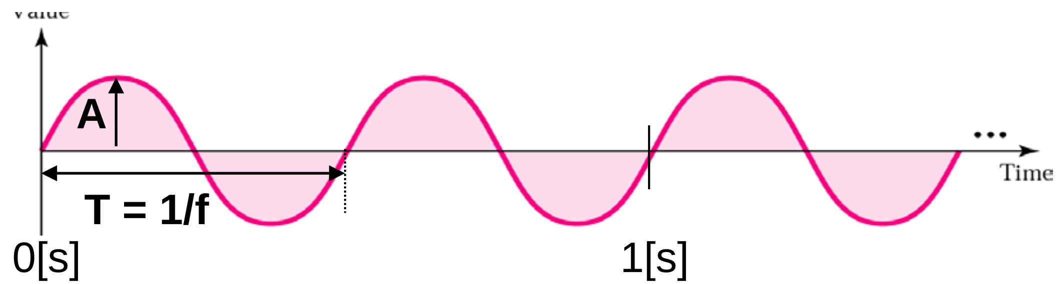
$$s(t) = A \cdot \sin(2\pi f t + \varphi)$$

(1.1) peak amplitude (A) – absolute value of signal's highest intensity – unit: volts [V]

(1.2) frequency (f) – number of periods in one second – unit: hertz [Hz] = [1/s] – inverse of period (T)!

(1.3) phase (φ) – absolute position of the waveform relative to an arbitrary origin – unit: degrees [º] or radians [rad]

The origin is usually taken as the last previous passage through zero from the negative to the positive direction.



(2) Composite Analog Signal – composed of multiple sinewaves

Simple Analog Signals

Sine wave pattern occurs often in nature, including ocean waves, sound waves, and light waves.

The oscillation of an undamped spring-mass system around the equilibrium is a sine wave

https://en.wikipedia.org/wiki/Sine_wave

2.3.4 Simple Harmonic Motion (SHM)

Sinusoidal waves are not mathematical abstractions, they can be produced in the real world by a phenomenon called **Simple Harmonic Motion** (SHM). An SHM is a specific type of oscillation exhibited by the spring loaded weight in Fig. 2.7. Assume that point P is rotating along a circle with uniform speed. A spring loaded weight *W* is attached to the point P with a flexible string T. As P moves along the circle in the anti-clockwise direction, the weight *W* attached to P oscillates up and down in synchronism. If a pen is attached to the backside of *W* which marks on a paper moving slowly to the right to represent the flow of time, the pen would trace out a sinusoidal curve. If ω is the angular frequency of the point *P* in radian/sec, then the frequency of the generated wave is given by:

$$f = \omega/2\pi$$

where f is in cycles/sec. This is apparent from Fig. 2.7, because as a complete cycle is traced out by the weight *W*, the point P moves by 2π radians, i.e. a complete circle. In 1 second since f cycles are traced out, the points moves a total of $2\pi f$ radians, which by definition is the angular frequency ω.

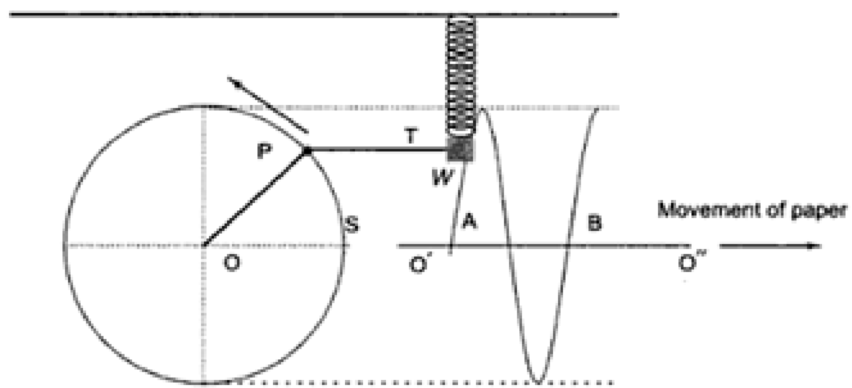


Figure 2.7 *Simple Harmonic Motion (SHM)*

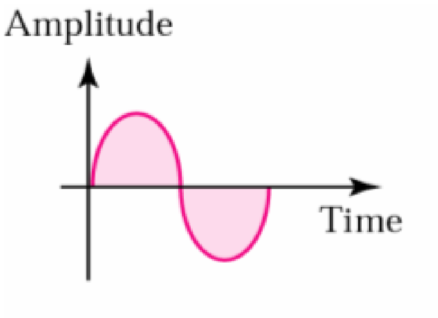
From "Principles of Multimedia" Googlebooks, by Ranjan Parekh

Simple Analog Signals

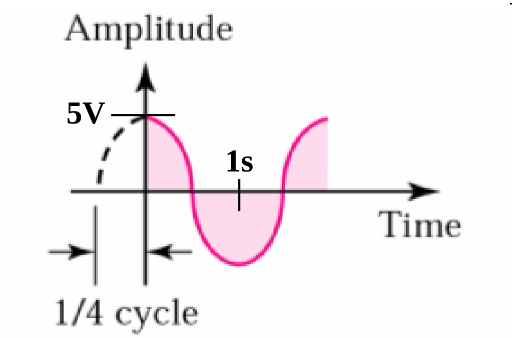
Phase in Simple Analog Signals

– measured in degrees or radians

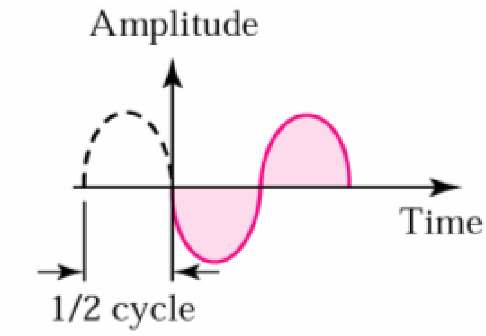
- 360º = 2π rad
- 1º = 2π/360 rad
- 1 rad = (360/2π)º = 57.29578°
- phase shift of 360º = shift of 1 complete period
- phase shift of 180º = shift of 1/2 period
- phase shift of 90º = shift of 1/4 period



φ = 0º or 360º



φ = 90º



φ = 180º

Analog Signals

Example [period (T) and frequency (f)]

Unit	Equivalent	Unit	Equivalent
seconds (s)	1 s	hertz (Hz)	1 Hz
milliseconds (ms)	10^{-3} s	kilohertz (KHz)	10^{3} Hz
microseconds (μs)	10^{-6} s	megahertz (MHz)	10^{6} Hz
nanoseconds (ns)	10^{-9} s	gigahertz (GHz)	10^{9} Hz
picoseconds (ps)	10^{-12} s	terahertz (THz)	10^{12} Hz

units of period and respective frequency

(a) Express a period of 100 ms in <u>micro</u>seconds.

$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 100 \times 10^{-3} \times 10^{6} \text{ μs} = 10^{5} \text{ μs}$

(b) Express the corresponding frequency in <u>kilo</u>hertz.

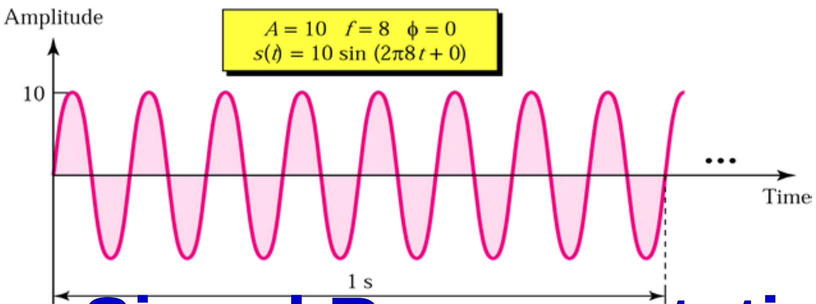
$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$

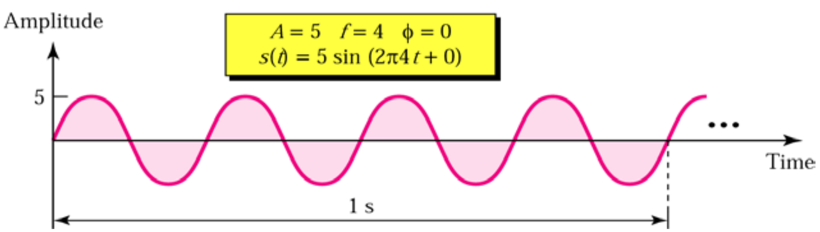
$f = 1/10^{-1} \text{ Hz} = 10 \times 10^{-3} \text{ KHz} = 10^{-2} \text{ KHz}$

Simple Analog Signals

Frequency in Simple Analog Signals – rate of signal change with respect to time

- change in a short span of time ⇒ f=??
- change over a long span of time ⇒ f=??
- signal does not change at all ⇒ f=?? ??
- signal changes instantaneously ⇒ f=?? ??





Signal Representation in Frequency Domain

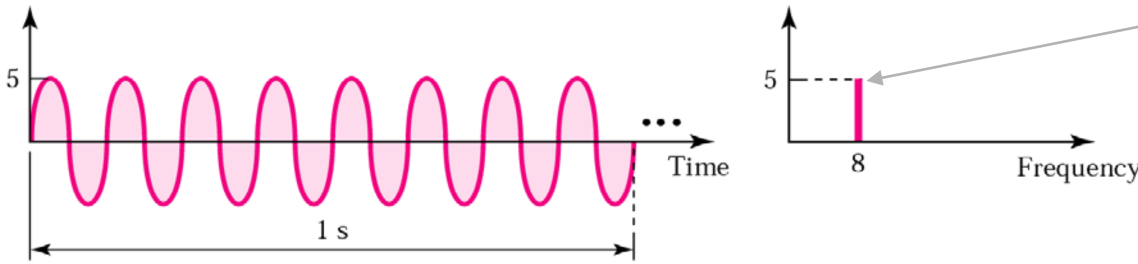
Time Domain Plot – specifies signal amplitude at each instant of time

- does NOT express explicitly signal's phase and frequency

Frequency Domain Plot – specifies peak amplitude with respect to freq.

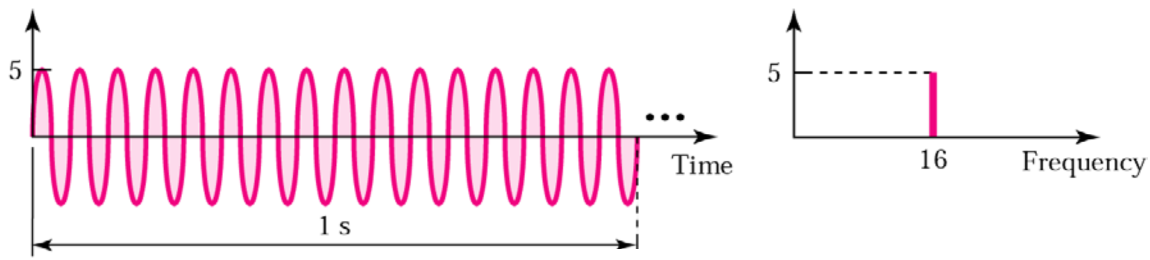
- phase CANNOT be shown in the frequency domain

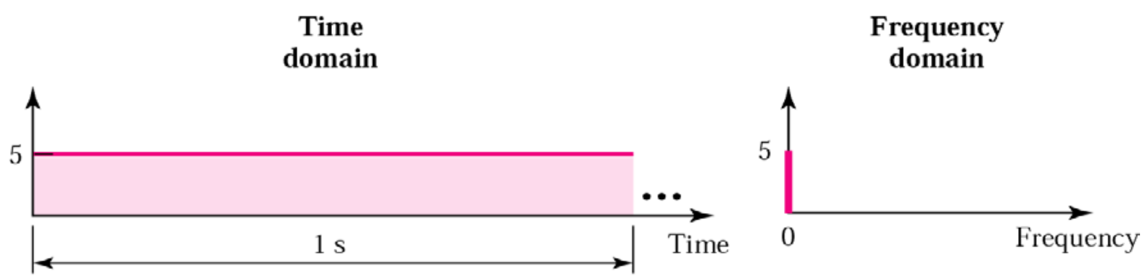
Simple Analog Signals



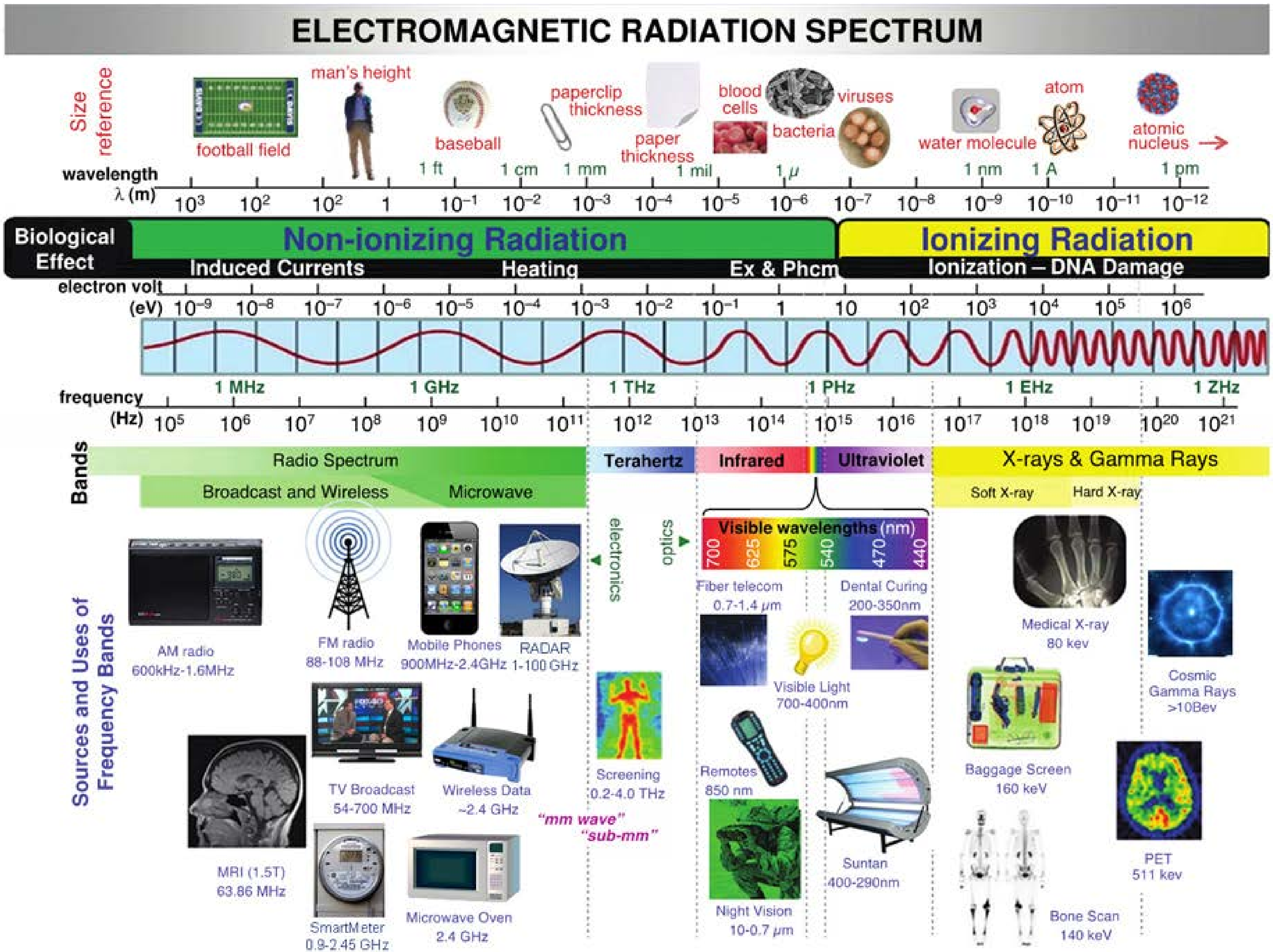
b. A signal with frequency 8

One ‘spike’ in frequency domain shows two characteristics of the signal:
spike position = signal frequency,
spike height = peak amplitude.





Analog signals are best represented in the frequency domain.



http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html

http://www-tc.pbs.org/wgbh/nova/assets/swf/1/electromagnetic-spectrum/electromagnetic-spectrum.swf

Composite Analog Signals

Fourier Analysis – **any composite signal can be represented as a combination of simple sine waves with different frequencies, phases and amplitudes**

$$s(t) = A_1 \sin(2\pi f_1 t + \varphi_1) + A_2 \sin(2\pi f_2 t + \varphi_2) + \ldots$$

- **periodic composite signal (period=T, freq.= f_0=1/T) can be represented as a sum of simple sines and/or cosines known as *Fourier series*:**

$$s(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty} \left[A_n \cos(2\pi n f_0 t) + B_n \sin(2\pi n f_0 t) \right]$$

With the aid of good table of integrals, it is easy to determine the frequency-domain nature of many signals.

$$A_n = \frac{2}{T} \int_0^T s(t) \cos(2\pi n f_0 t) dt, \quad n = 0,1,2, \ldots$$

$$B_n = \frac{2}{T} \int_0^T s(t) \sin(2\pi n f_0 t) dt, \quad n = 1,2,3, \ldots$$

- **f_0 is referred to as 'fundamental frequency'**
- **integer multiples of f_0 are referred to as harmonics**

Composite Analog Signals (cont.)

Angular Frequency – **aka radian frequency – number of 2π revolutions during a single period of a given signal**

$$\omega = \frac{2\pi}{T} = 2\pi \cdot f$$

- **simple multiple of ordinary angular frequency**

$$s(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty} \left[A_n \cos(n\omega_0 t) + B_n \sin(n\omega_0 t) \right]$$

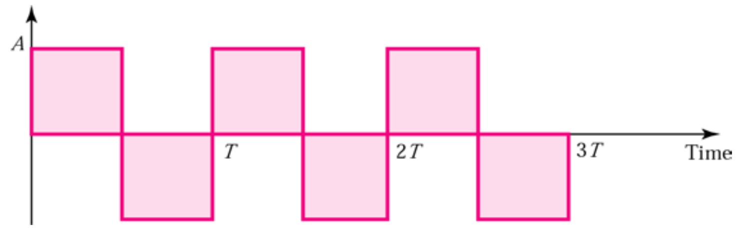
$$A_n = \frac{2}{T}\int_0^T s(t)\cos(n\omega_0 t)dt, \qquad n = 0,1,2,...$$

$$B_n = \frac{2}{T}\int_0^T s(t)\sin(n\omega_0 t)dt, \qquad n = 1,2,...$$

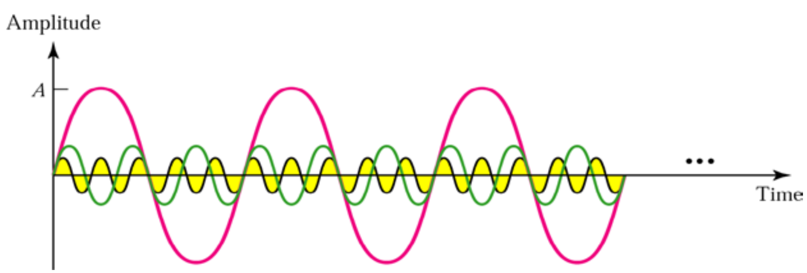
Composite Analog Signals (cont.)

Example **[periodic square wave]**

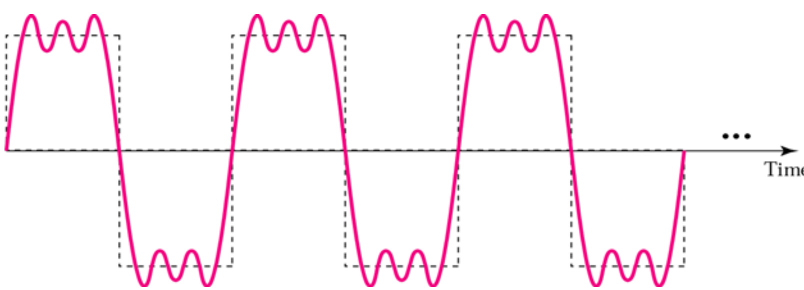
No DC component!!!



$$s(t) = \frac{4A}{\pi}\sin(2\pi ft) + \frac{4A}{3\pi}\sin(2\pi(3f)t) + \frac{4A}{5\pi}\sin(2\pi(5f)t) + \ldots$$



three harmonics



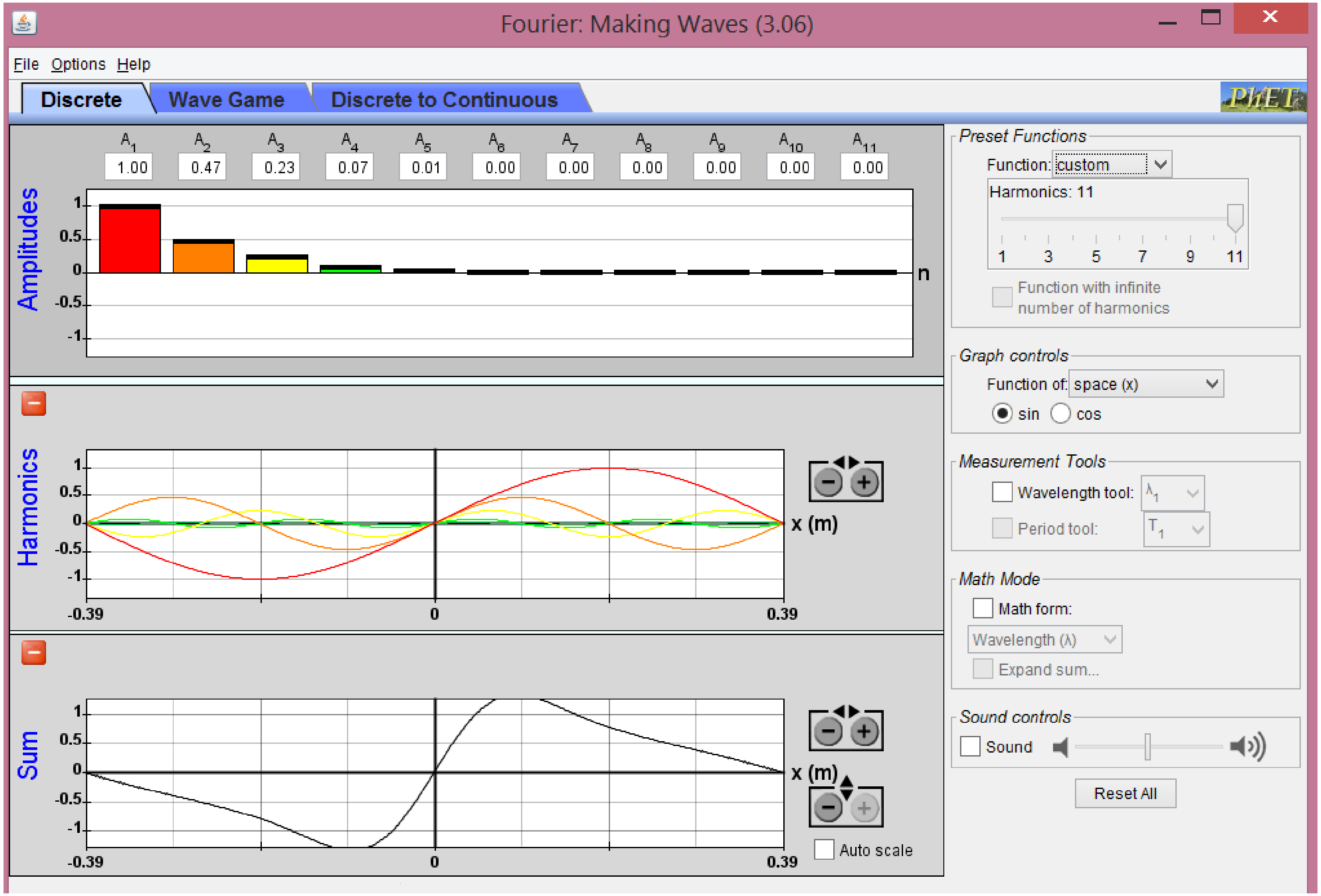
adding three harmonics

With three harmonics we get an approximation of a square wave.
To get the actual square, all harmonics up to ∞ should be added.

https://en.wikipedia.org/wiki/File:Fourier_series_square_wave_circles_animation.gif
http://www.acs.psu.edu/drussell/Demos/Fourier/Fourier.html
http://www.nickkasprak.com/blog/fourier-series-animator

Composite Analog Signals (cont.)

Example [composite analog signal]



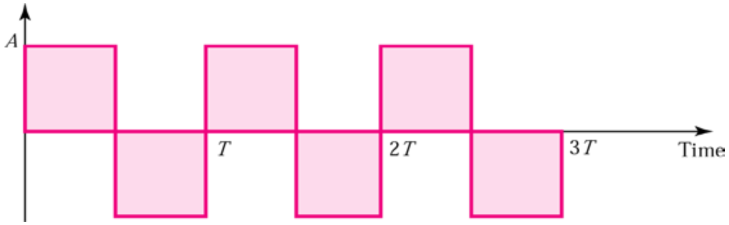
https://phet.colorado.edu/en/simulation/fourier

Composite Analog Signals (cont.)

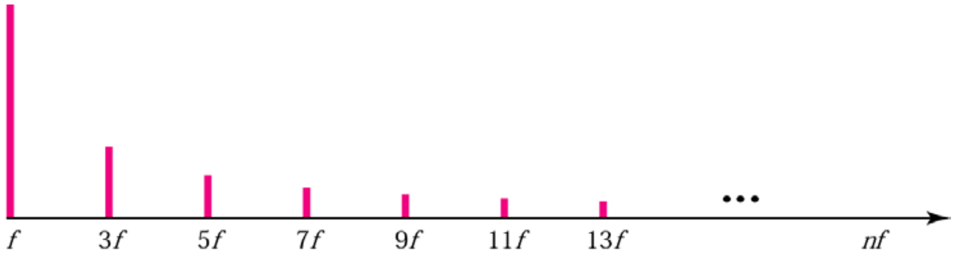
Frequency Spectrum of Analog Signal – range (set) of frequencies that signal contains

Absolute Bandwidth of Analog Signal – width of signal spectrum: $B = f_{highest} - f_{lowest}$

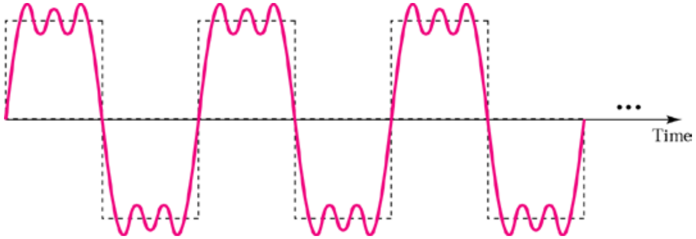
Effective Bandwidth of Analog Signal – range of frequencies where signal contains most of its power/energy



square wave



a. Frequency spectrum of a square wave



3-harmonic representation

b. Frequency spectrum of an approximation with only three harmonics

Composite Analog Signals (cont.)

Example **[frequency spectrum and bandwidth of analog signal]**

A periodic signal is composed of five sinewaves with frequencies of 100, 300, 500, 700 and 900 Hz.

What is the bandwidth of this signal?

Draw the frequency spectrum, assuming all components have a max amplitude of 10V.

Solution:

$$B = f_{highest} - f_{lowest} = 900 - 100 = 800 \text{ Hz}$$

The spectrum has only five spikes, at 100, 300, 500, 700, and 900.