Digital Signal Processing

A host of technologies touching many interdisciplinary areas

- **What is a signal?**
  a. An agreed upon message that triggers action or carries information
  b. A message that conveys notice or warning
  c. An electronic message conveyed by telephone, radio, radar, or television
  d. A measurable physical quantity (e.g. voltage, current, magnetic field)
- **What is a digital signal?** An array of measurements
- **Examples of Signal Processing?** Stock market prices, streaming of video, data mining, natural language processing, data compression, image processing, earthquake prediction, medical diagnosis, etc.
- **Interdisciplinary aspects**: Physics, Engineering, Psychology, Mathematics, Computer Science, Cognition, Biology, etc.
- **Processing algorithms**: breaks down to twiddling single and multi dimension arrays; often algorithms result in small amounts of code, which is heavy in mathematics/statistics
- **Difficulties**: Signals are often imprecise and have many redundancies

Digital Signal Processing (DSP)

- **Radar and Sonar**
  – What signal comes back?
- **Image Processing**
  – Transmit & reconstruct
- **Linguistics**
  – Recognize & Synthesis
- **Algorithms**
  – Compress and encrypt, noise removal, filter
- **Music**
  – Synthesis and edit
- **Military:**
  – Secure channels, laser bombs
- **Exploration:**
  – oil, minerals, ocean mapping
- **Climate:**
  – Earthquake, weather patterns
- **Grand Challenges**
  – Real world simulations
- **Medical**
  – Medical Resonance Imaging

Applications: Cell Phones, voice mail, phone support, web translation, and many more.

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Signal Redundancy

- Continuous signal (virtually infinite)
- Sampled representations of speech
  - **Mac**: 44,100 2-byte samples per second (705kbps)
  - **PC**: 16,000 2-byte samples per second (256kbps)
  - **Telephone**: 4k 1-byte sample per second (32kbps)
  - **CELP Audio Compression Algorithm**: 8kbps
  - **Research**: 4kbps, 2.4 kbps
  - **Military applications**: 600 bps
  - **Human brain**: 50 bps

Definition: Sampling Rate is the number of measurements per second

Noise

- **Definition:** Random electrical or acoustic activity that obscures communication

- **Noise impact on speech**
  - Noise degrades the speech recognition effectiveness
  - Consider construction noise outside the window
  - How much noise makes normal speech unintelligible?
  - What do human beings do to compensate?

- **Automated Solution**
  - Apply appropriate filters to eliminate noise from signals
  - Effective filters must not destroy essential signal data

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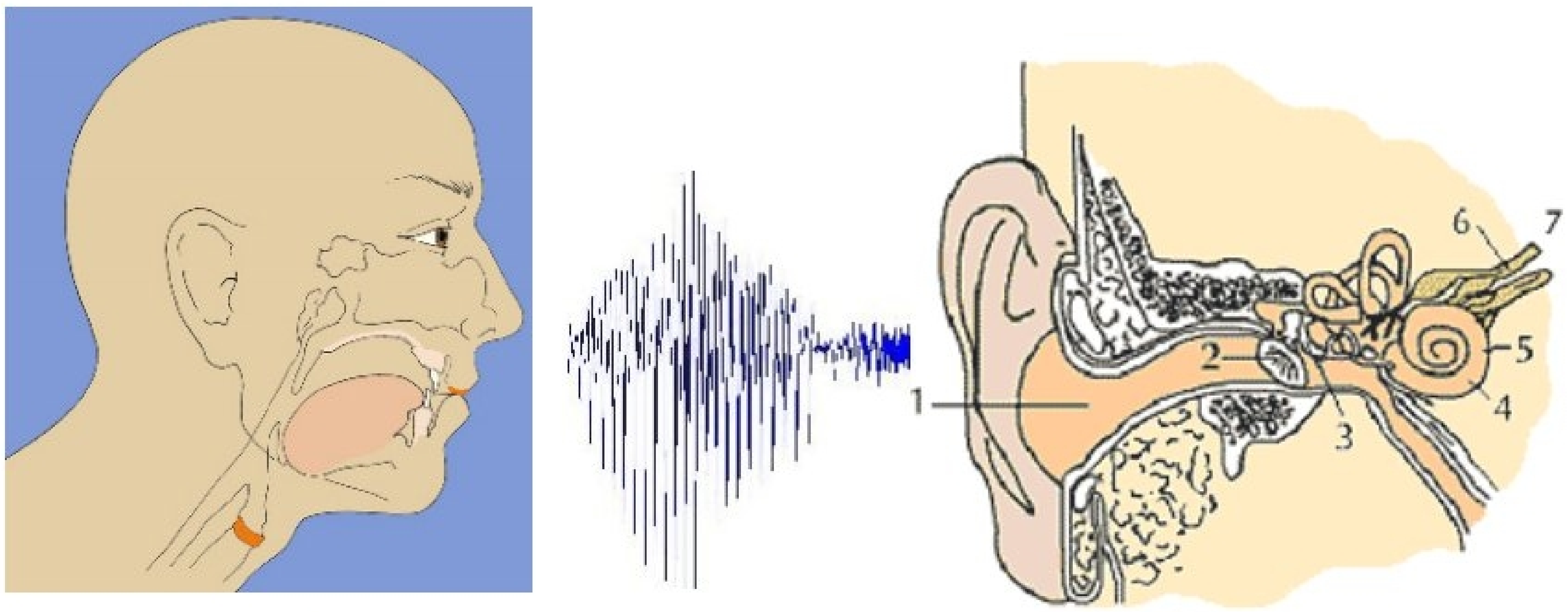
Natural Language Processing



The Noisy Channel

Computational Linguistics

1. Replace the vocal articulators with a synthesizer
2. Replace the ear with a receiver
2. Replace the brain with the computer

Could a computer process this?

I cdnuolt blveiee that I cluod aulaclty uesdnatnrd what I was rdgnieg.

The phaonmneal pweor of the hmuan mnid Aoccdrnig to rscheearch at Cmabridgde Uinervtisy, it deosn't mttaer in what oredr the ltteers in a word are, the olny iprmoatnt tihng is that the frist and lsat ltteer be in the rghit pclae.

The rset can be a taotl mses and you can still raed it wouthit a problem.

This is bcuseae the huamn mnid deos not raed ervey lteter by istlef, but the word as a wlohe.

Amzanig huh?

Yaeh and I awlyas thought slpeling was ipmorantt!

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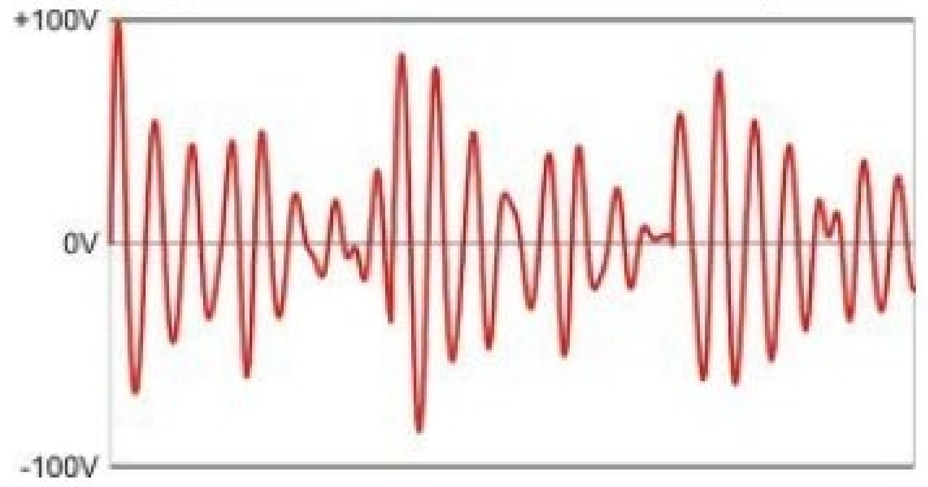
Discrete versus Continuous

- **Continuous (analog)**: A signal, typically found in nature, whose infinite values are represented by a mathematical function. That is given any point in time, if we know the initial conditions, we can compute a value at that point.
- **Discrete (digital)**: A sequence of measurements, each one separated by a fixed time interval.
- **Digital processing of continuous signals**
  – Computers deal with digital signals, because memory, though large, has a finite size.
  – Input devices measure signal strength thousands of times a second (e.g. audio: 44,100 is common). These values translate into a huge arrays in computer memory.

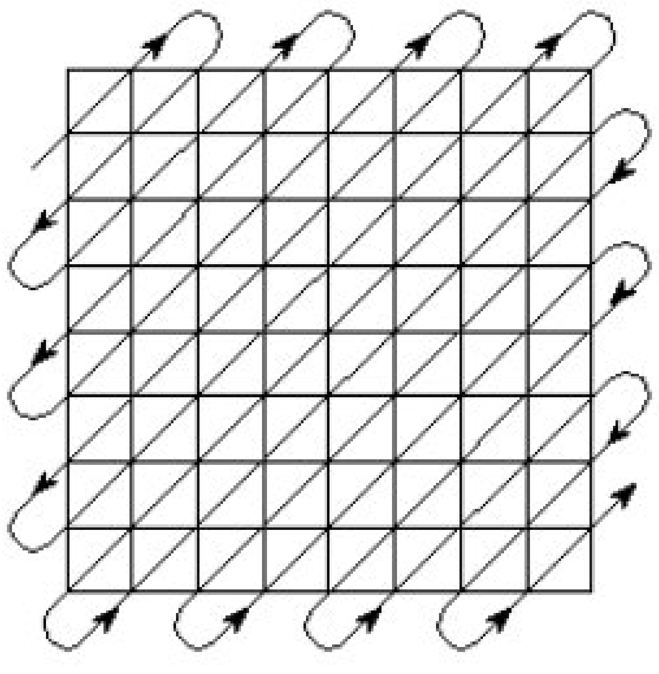
Signal Dimensionality

Note: Even higher dimension signals can be reduced to a single dimension

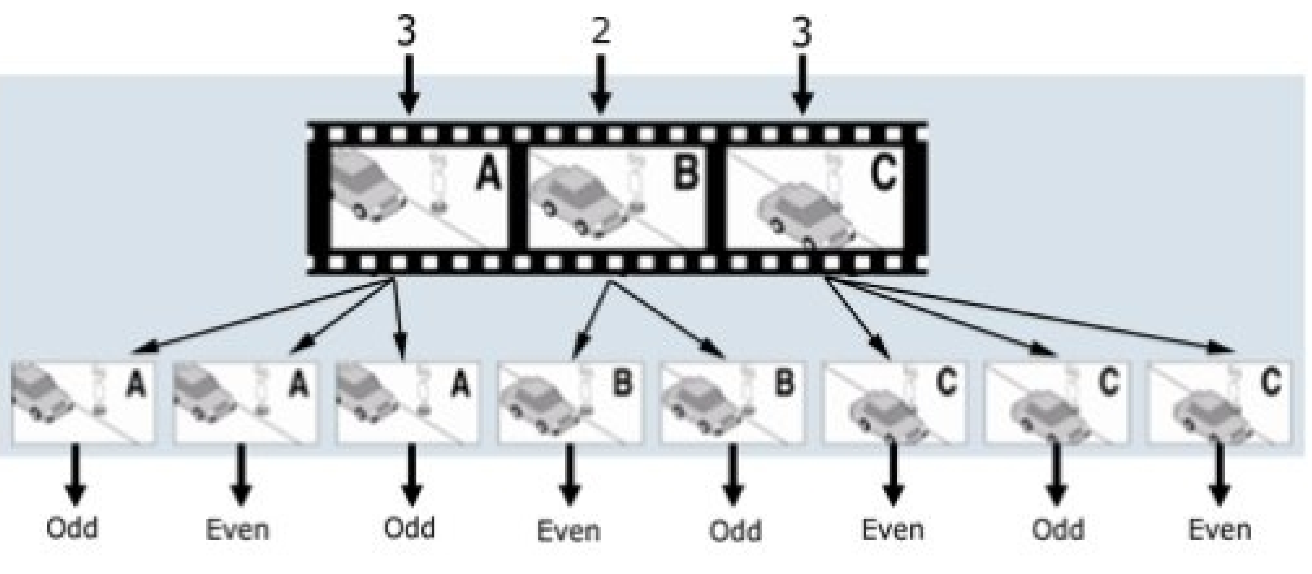
- Single Dimension (audio)



- Double Dimension (images)



- Three Dimensions (video)



- Higher Dimension (Climate Change Simulations)

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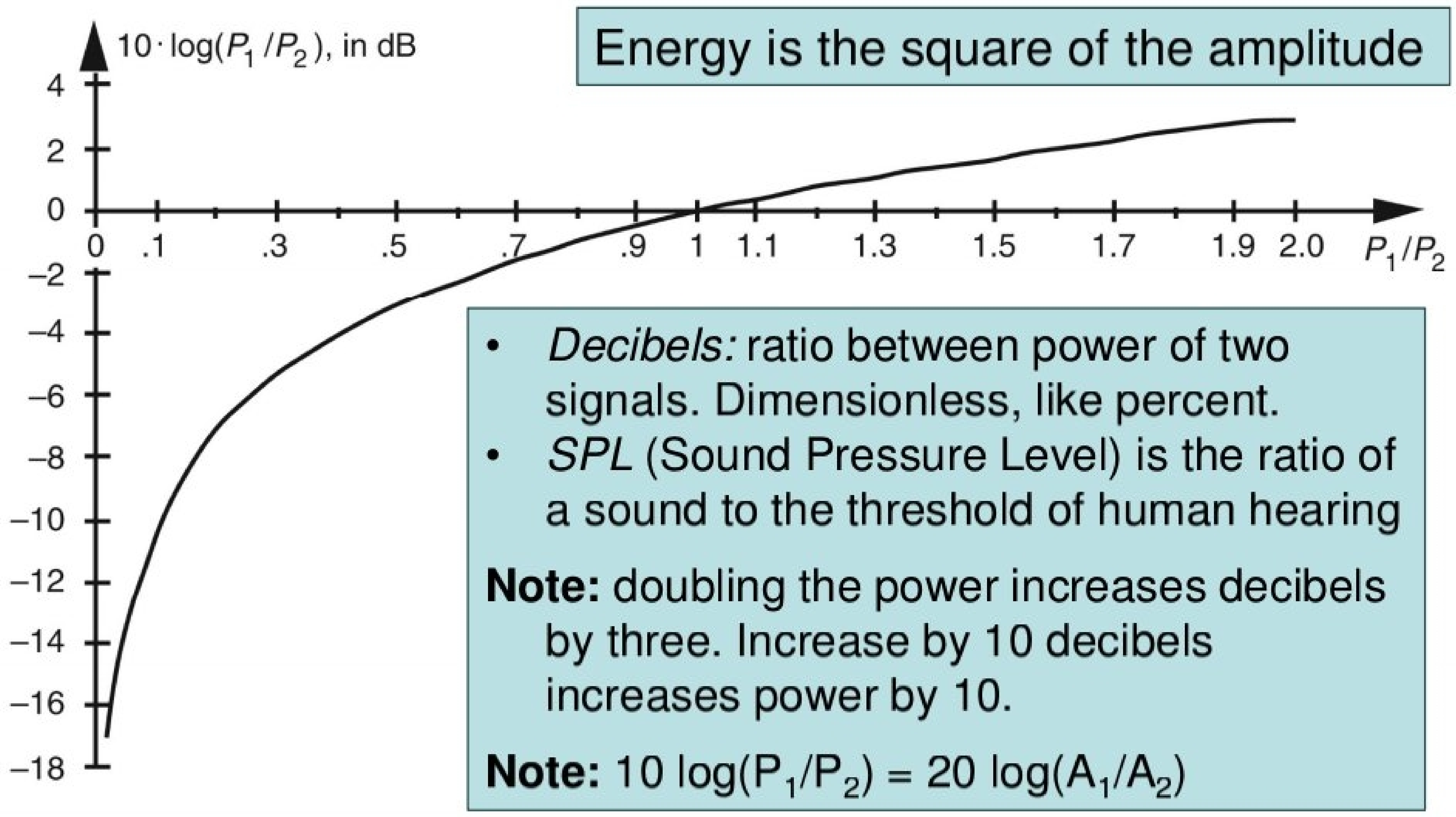
Signal Power (Energy)

Energy is the square of the amplitude



- *Decibels:* ratio between power of two signals. Dimensionless, like percent.
- *SPL* (Sound Pressure Level) is the ratio of a sound to the threshold of human hearing

Note: doubling the power increases decibels by three. Increase by 10 decibels increases power by 10.

Note: $10 \log(P_1/P_2) = 20 \log(A_1/A_2)$

Figure E–1 Logarithmic decibel function of Eq. (E–2).

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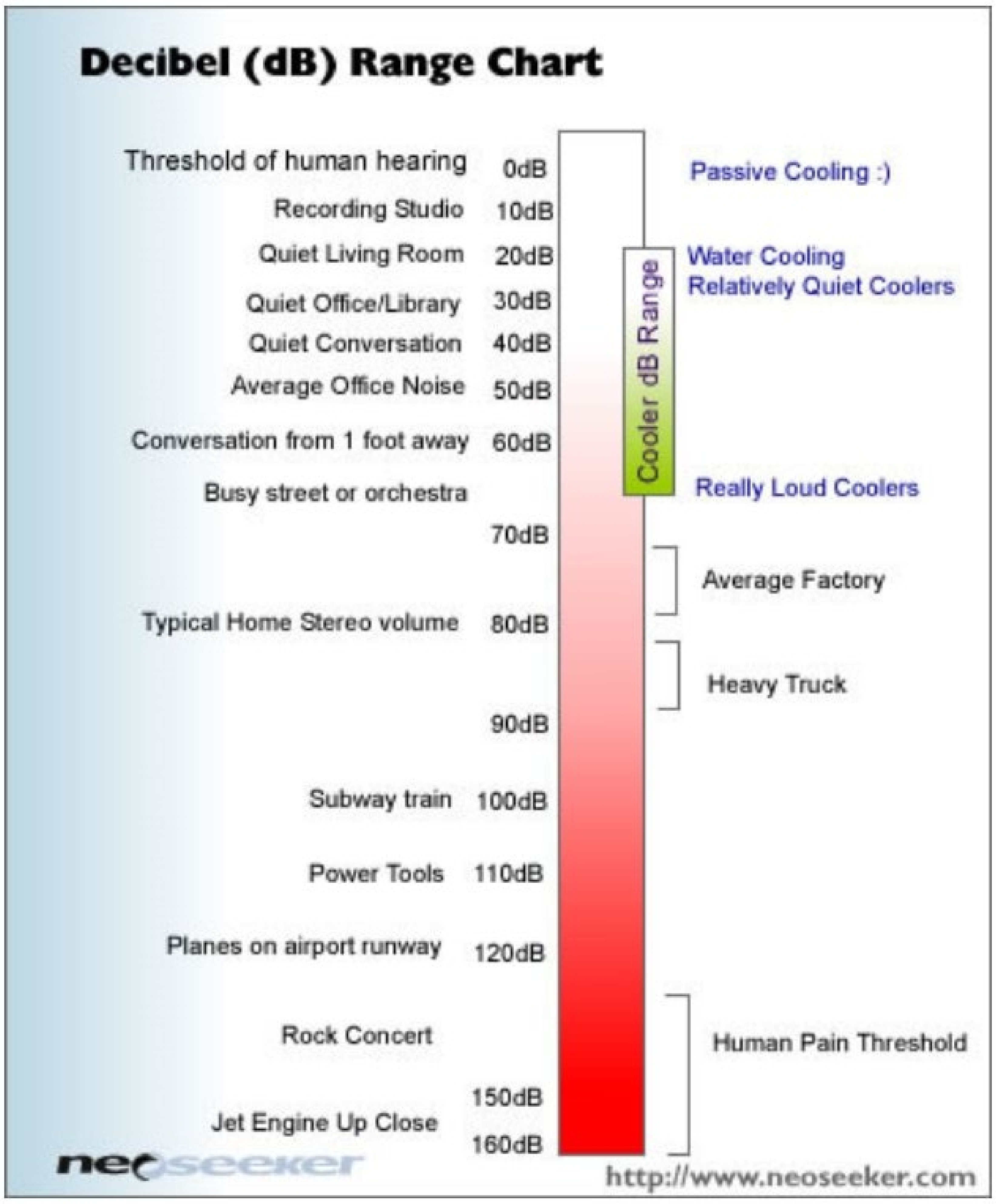
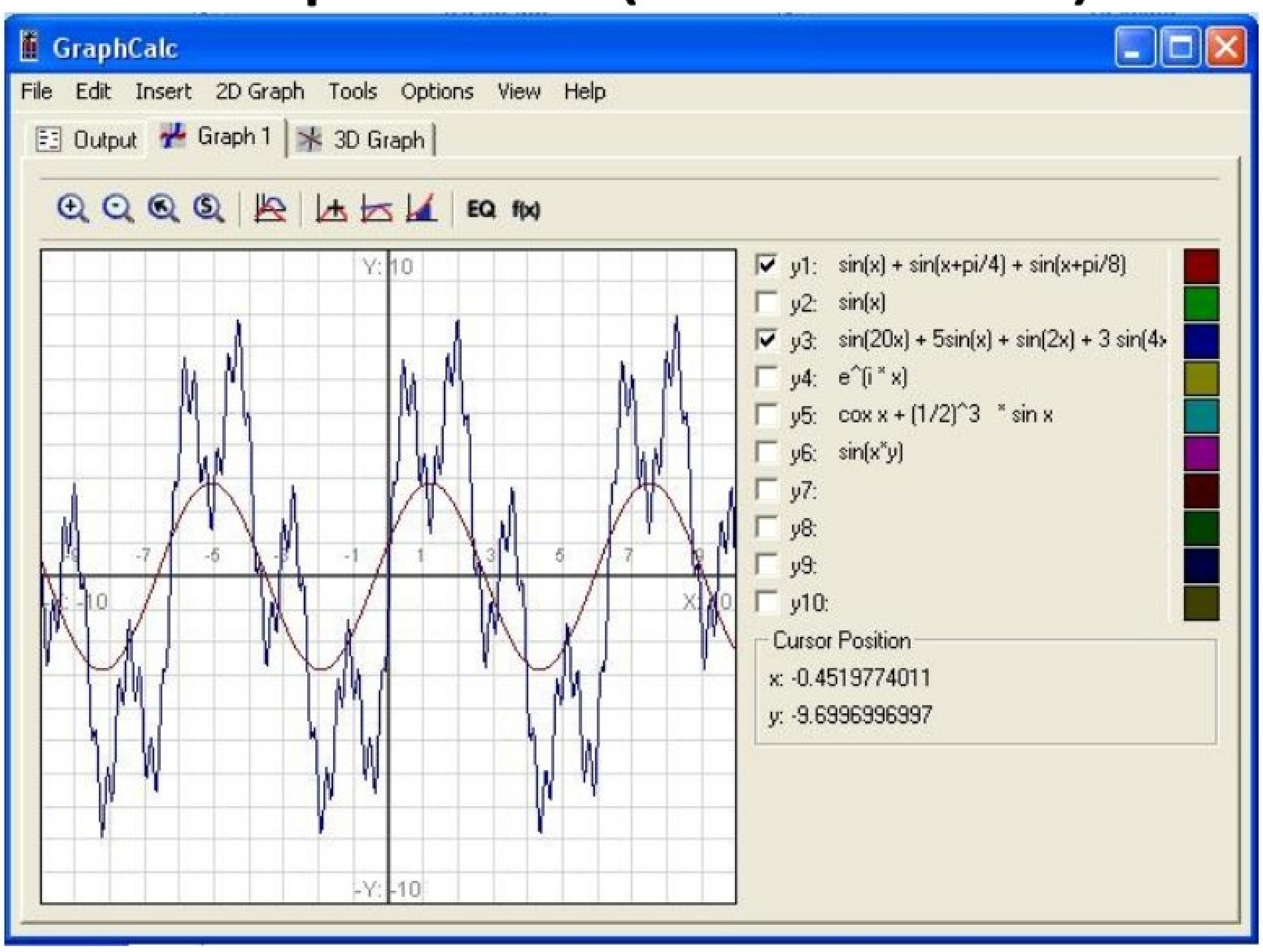


Sound	dB
TOH	0
Whisper	10
Quiet Room	20
Office	50
Normal conversation	60
Busy street	70
Heavy truck traffic	90
Power tools	110
Pain threshold	120
Sonic boom	140
Permanent damage	150
Jet engine	160
Cannon muzzle	220

Working with Signals

- Special purpose languages: MatLab, Octave
  - Matlab is very expensive, but available on campus
  - Octave, is largely compatible (but not entirely), and is free
- Free signal visualization programs: GraphCalc
- Sound Editing tools: ACORNS Sound Editor, Audacity. Sound Editor source is available to the class
- Java based resources: Java Sound, Tritonus

GraphCalc (Freeware)



Good for creating and visualizing signals

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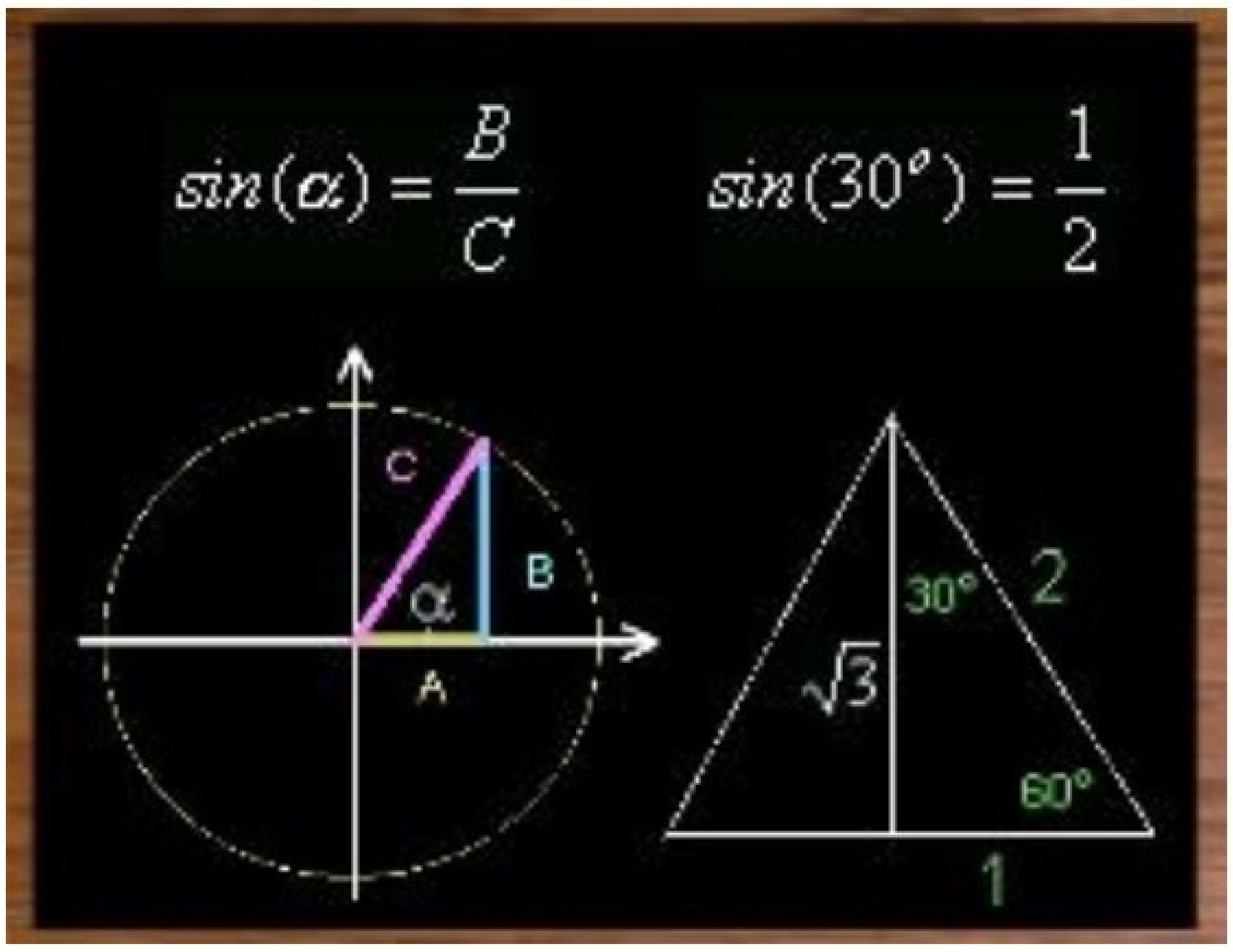
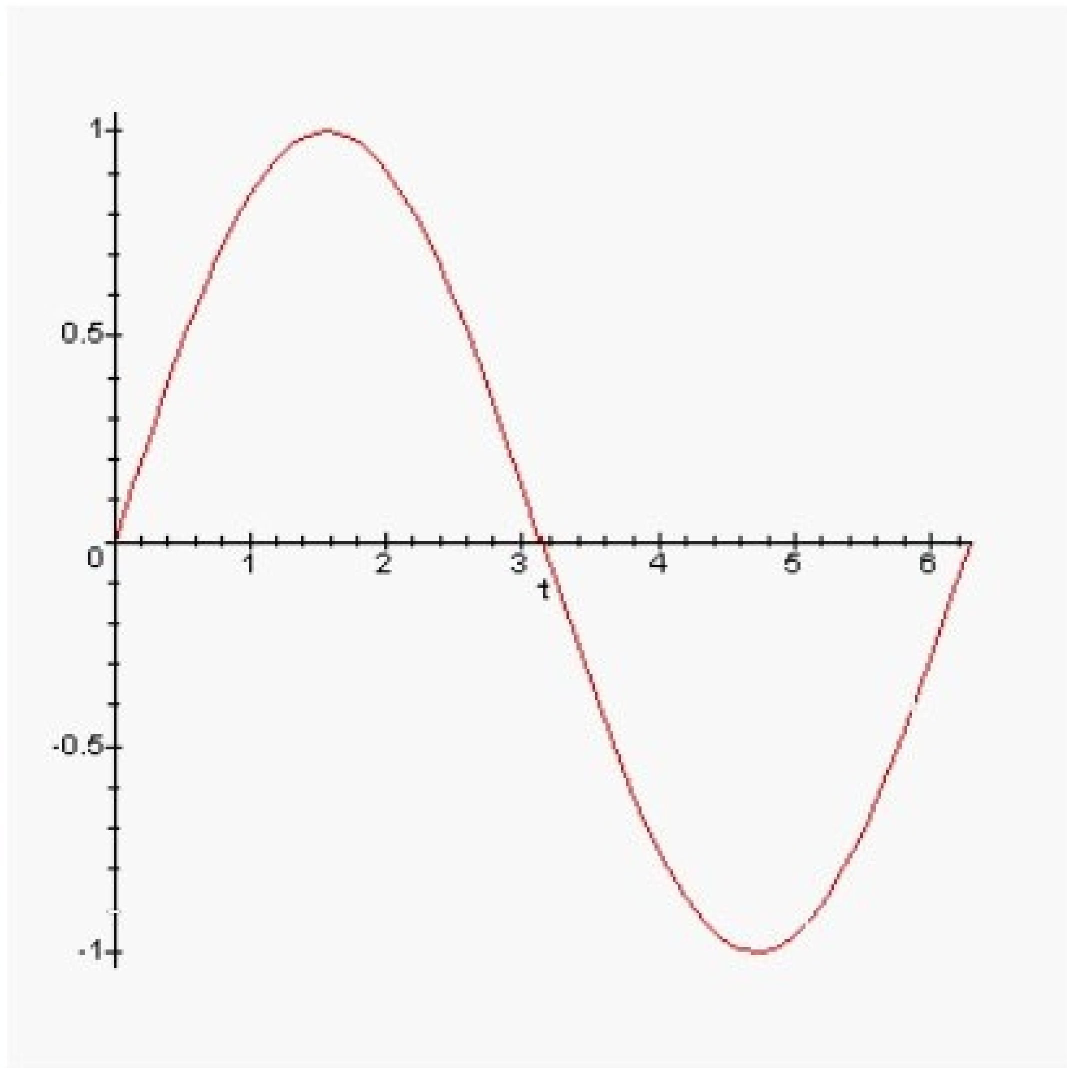
Understanding Sine Waves

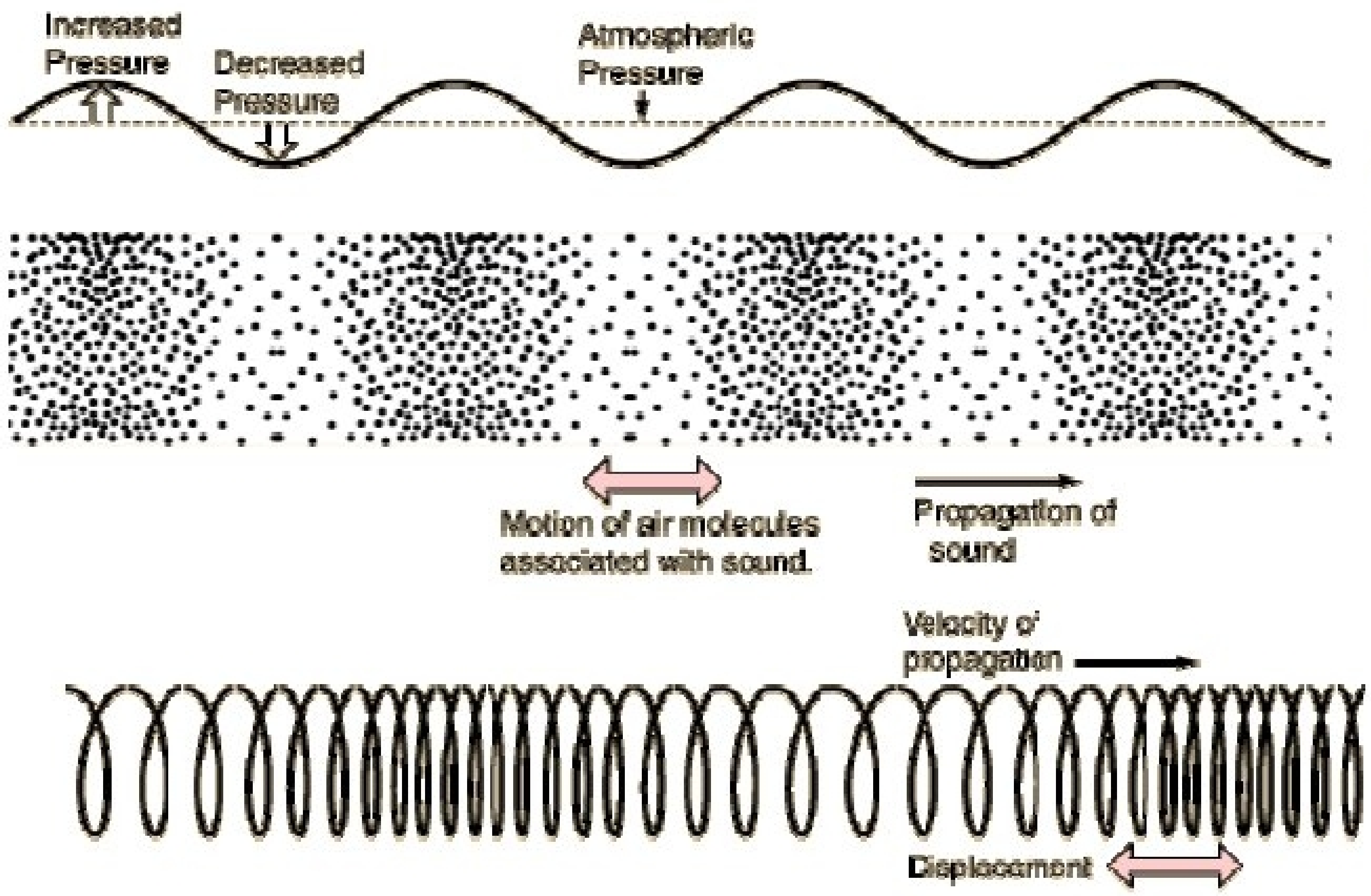
- Sine is the ratio of the height to the hypotenuse
- Many phenomena in nature occur in sine wave patterns

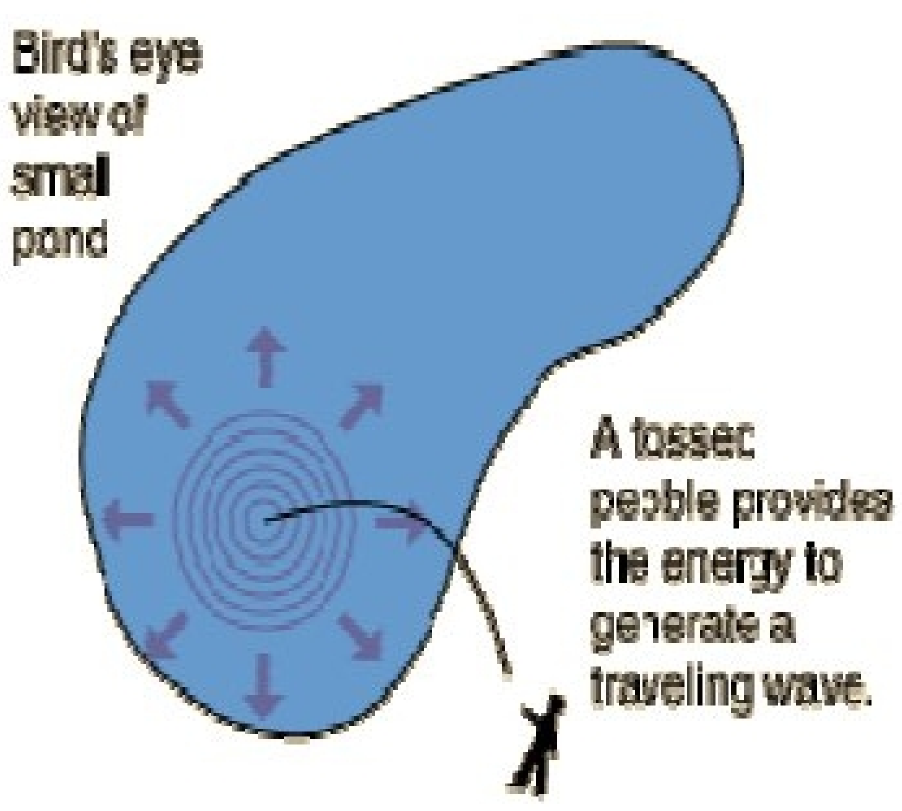




Basic Terminology – periodic signals

- Amplitude — The distance from zero to the maximum height
- Period — The time it takes for a sine wave to complete one cycle
- Frequency (Hz) — The repetitions or cycles per second (1/period)





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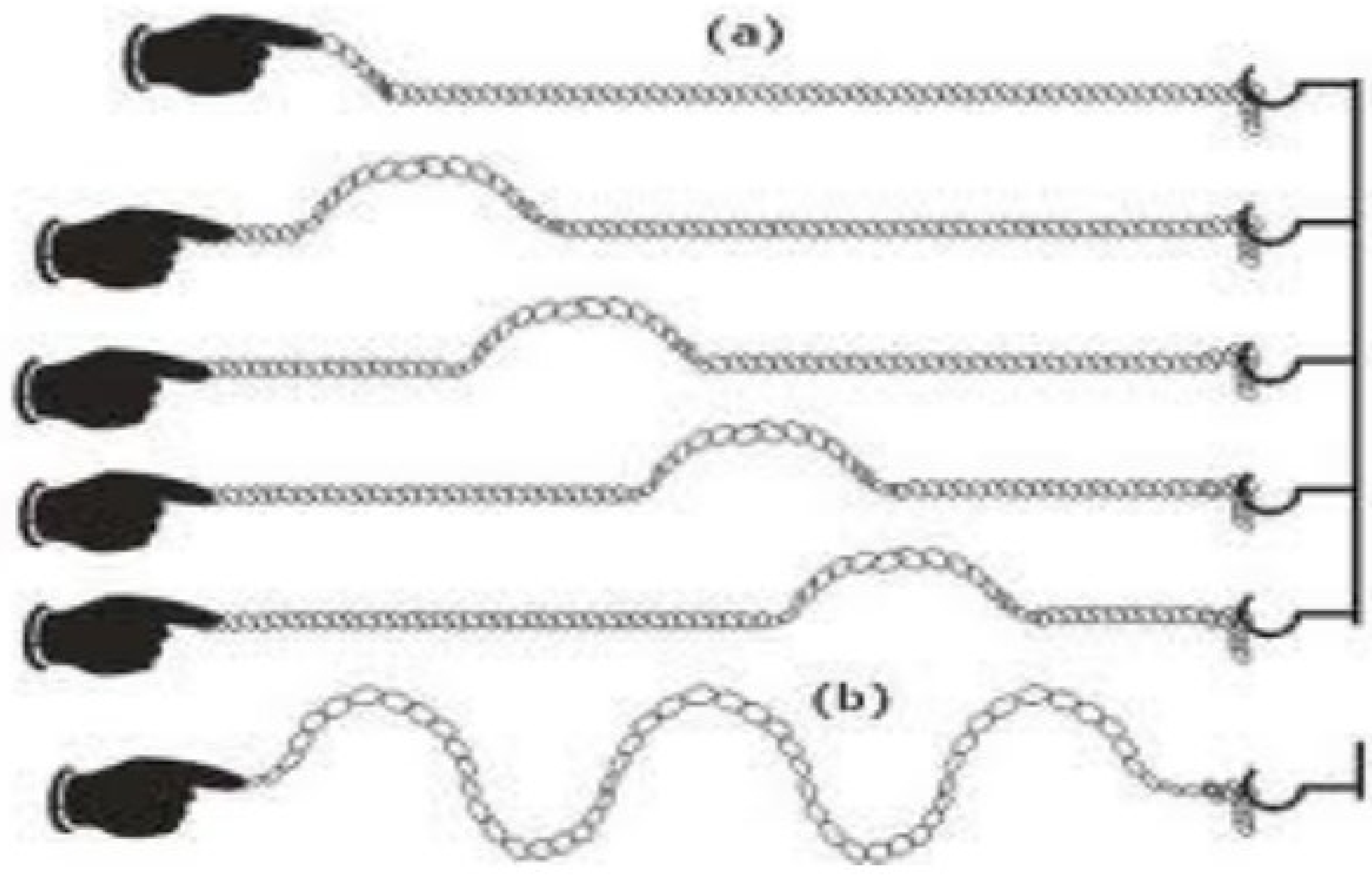
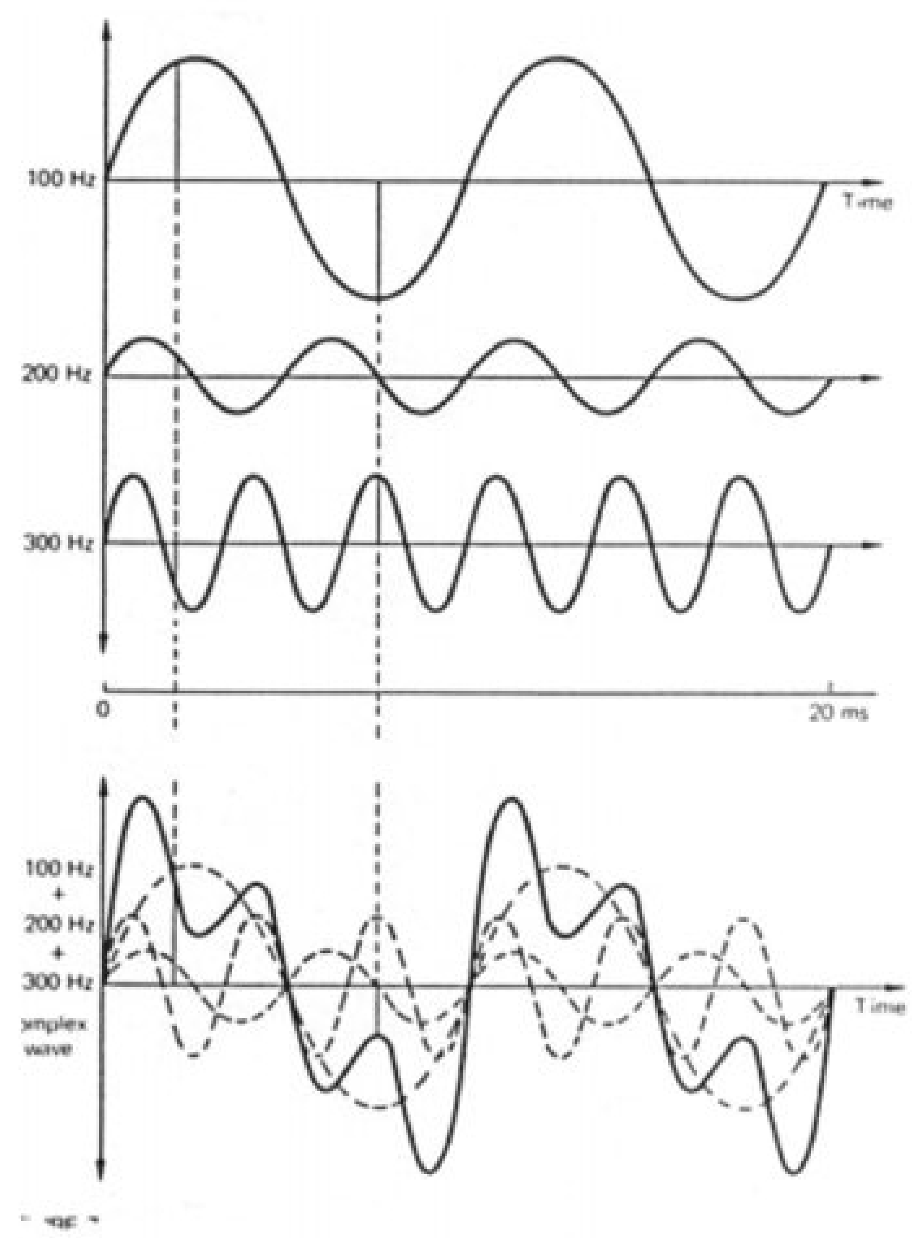
Rope Impulse Waves



- A hand jerk is an impulse starting the wave to travel.
  - Speed of hand jerk determines frequency
  - Rope stiffness determines wave velocity
  - Reverse waves starts at the fixed end, which can resonate if forward waves correlate, or cancel if they don't.
  - Eventually a steady state is reached and we perceive no motion

Complex Wave Patterns

- **Sound waves occupying the same space combine to form a new wave of a different shape.**
- **Harmonically related waves add together and can create any complex wave pattern.**
- **Harmonically related waves have frequencies that are multiples of a basic frequency.**



Note: All frequency waves do not have to start at zero, they can be "out of phase". The amount of shift in degrees is called their phase angle.

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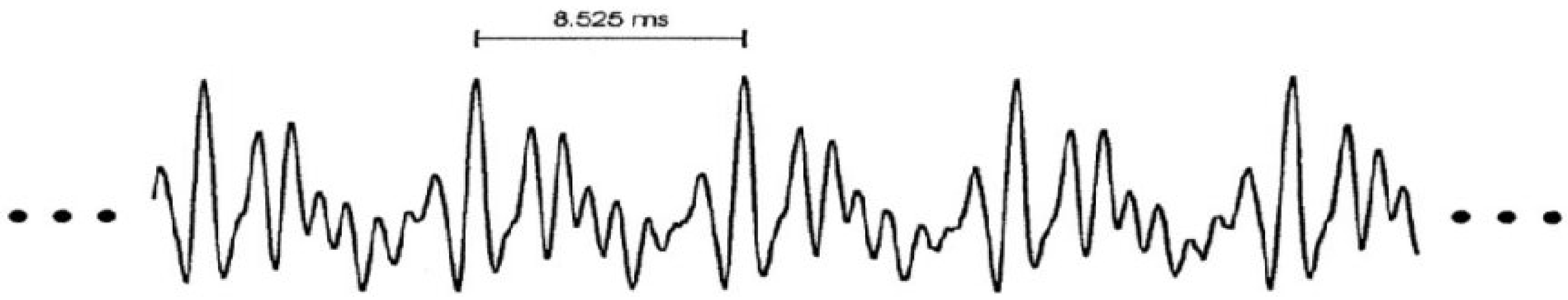
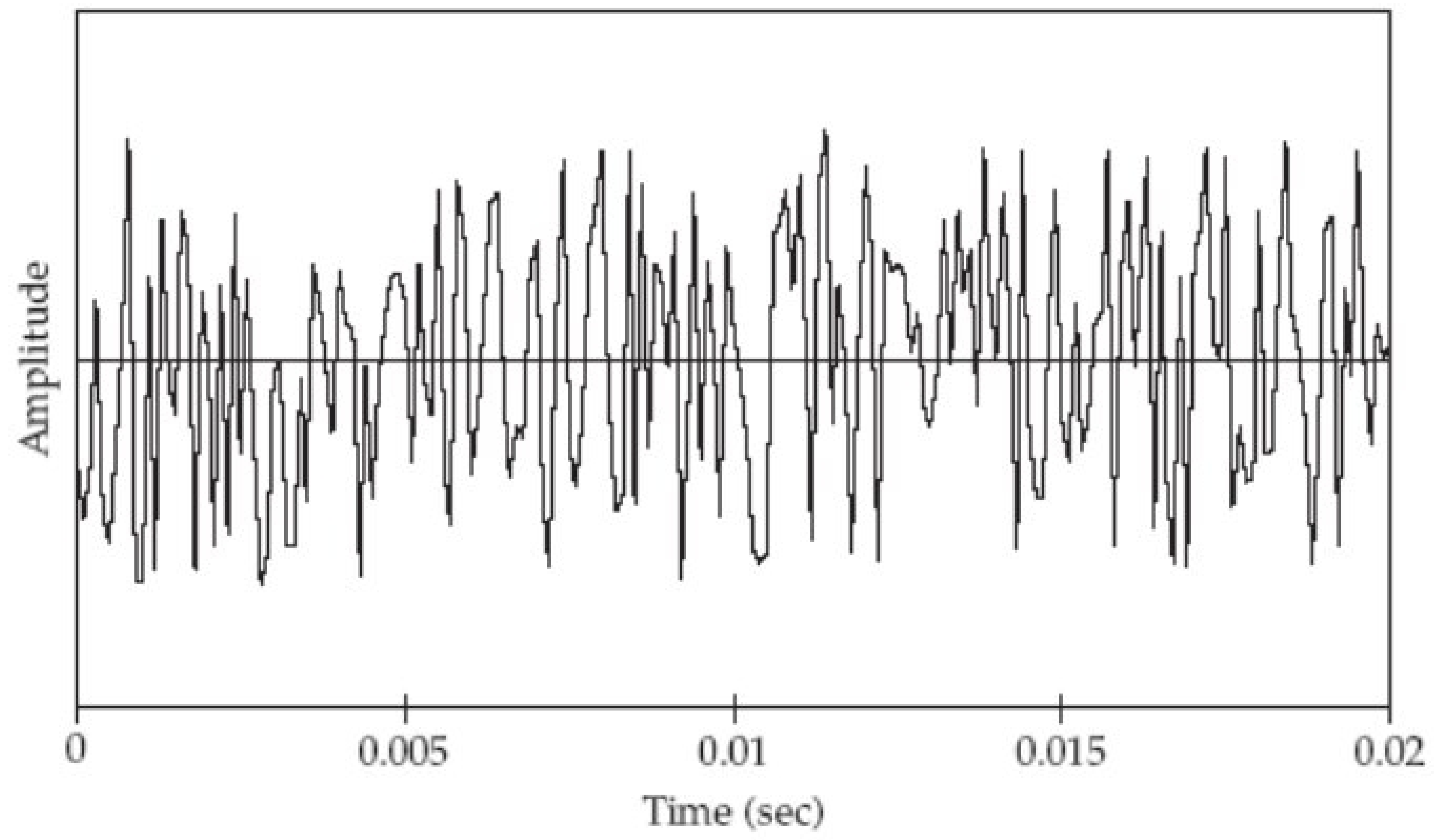
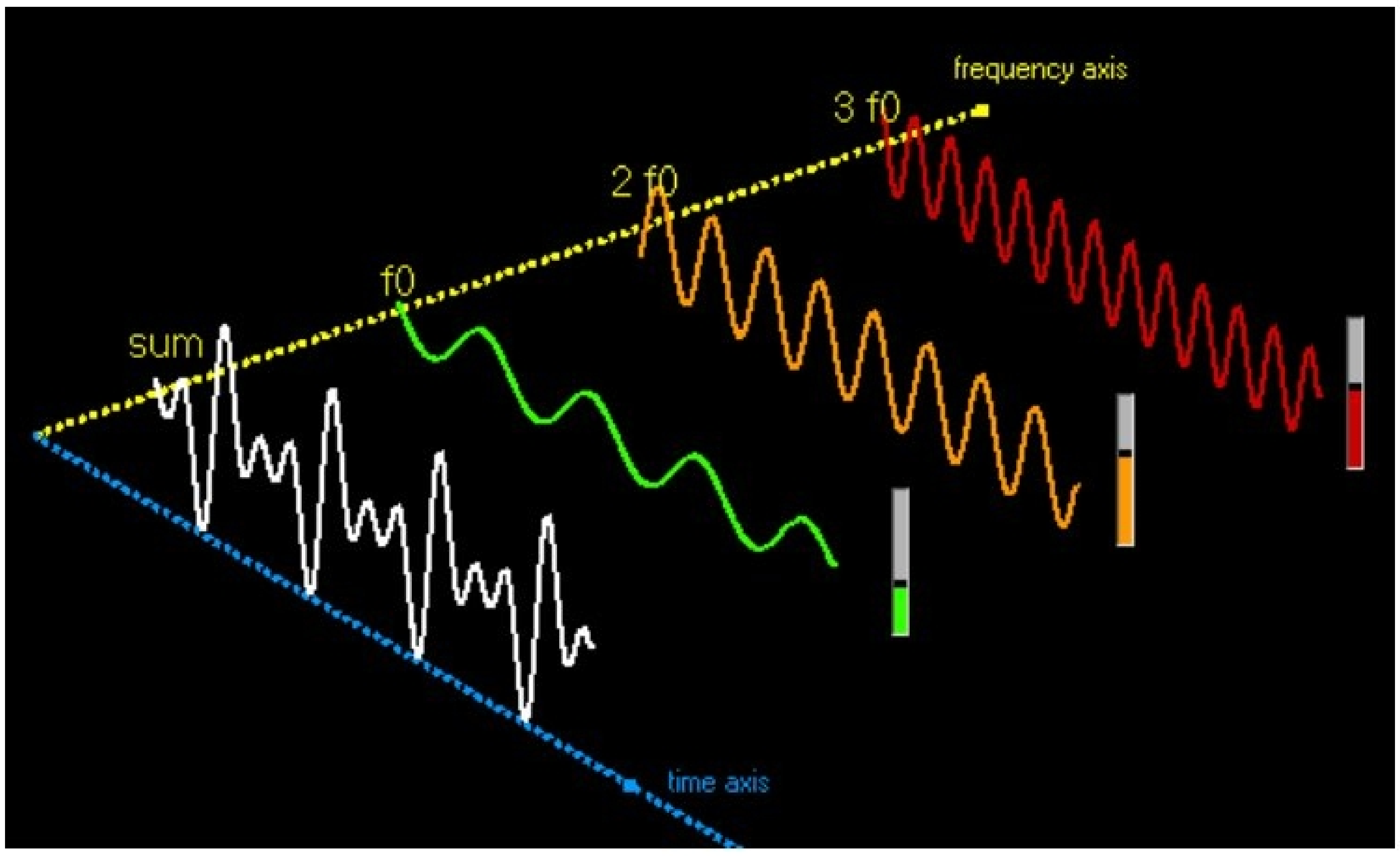
Complex Wave Examples





Time vs. Frequency Domain



Time Domain: A composite wave summing different frequencies
Frequency Domain: Split time domain into component frequencies

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Historical Note

- **Jean Baptist Joseph Fourier (1768-1830)**
  - **Paper submitted**: Academy of Science in Paris, 1807
  - **Claim**: All signals decompose into a sum of sine waves
- **The review committee**
  - Laplace (1749-1827) voted to accept
  - Lagrange (1736-1813) voted to reject. The claim did not account for waves with sharp corners
  - The paper never got published
- **Results**
  - Fourier was correct if we use an infinite series of waves
  - Lagrange was correct if we use a finite series of waves
  - Fourier analysis is the foundation for Digital Signal Processing (DSP)

Time and Frequency

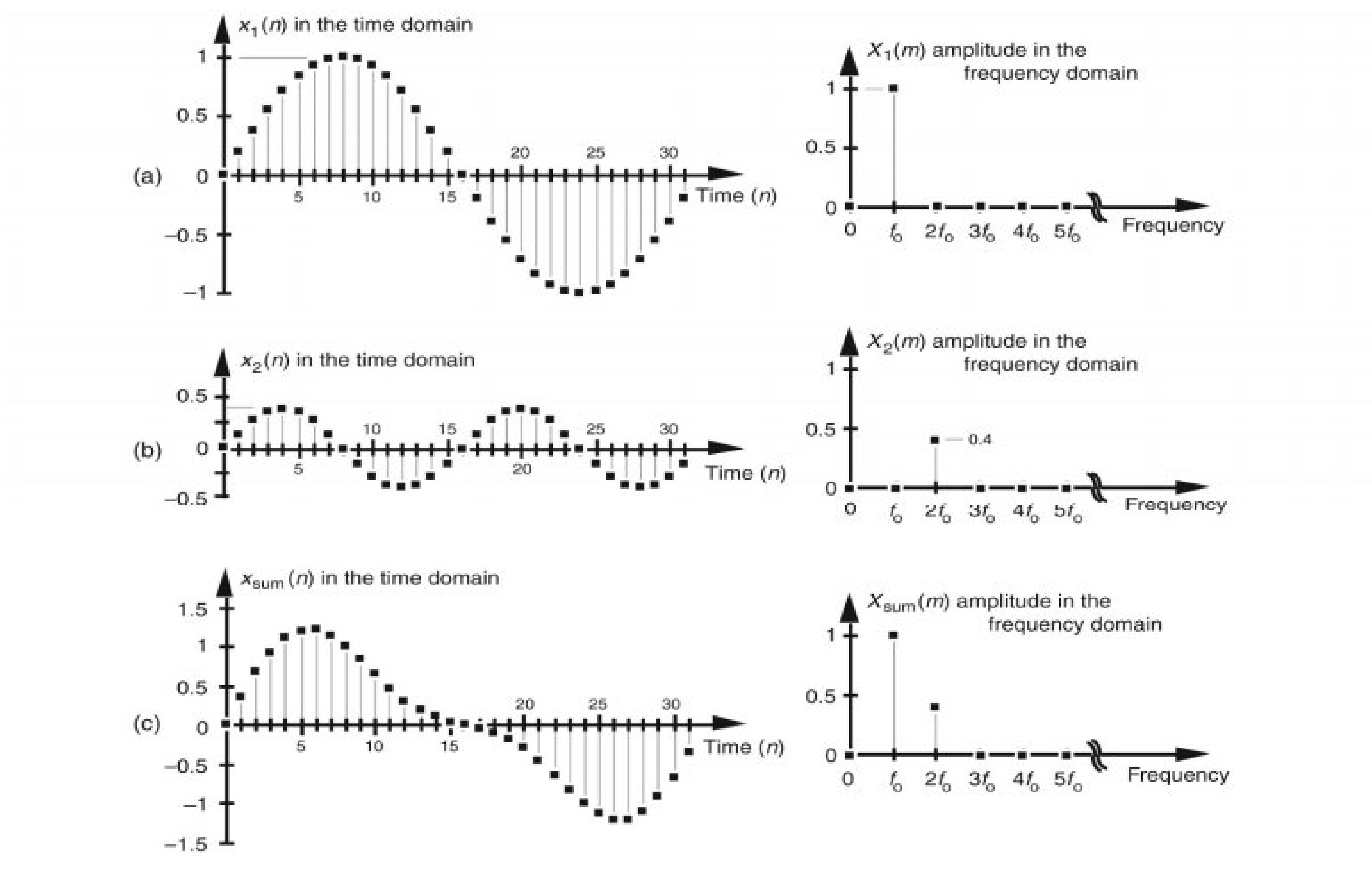

Figure 1–3 Time- and frequency-domain graphical representations: (a) sinewave of frequency f_o; (b) reduced amplitude sinewave of frequency $2f_o$; (c) sum of the two sinewaves.

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Non Periodic or Quasi-periodic

- Many signals change their characteristics over time
- Fourier showed that within smalls time windows, we can analyze signal chunks as if they were periodic
- Processing involves
  1. Chopping signals into overlapping "**frames**" of some millisecond width
  2. "**Window**" the frames, which means apply algorithms to smooth the abrupt edges
  3. Perform "**feature**" extraction algorithms on windowed frames to obtain set of numbers that functions like a frame's fingerprint
  4. Use the feature sets to perform additional processing

Quasi-periodic: Signals, that are somewhat periodic, but whose features slowly change over time

Signal Power or Energy

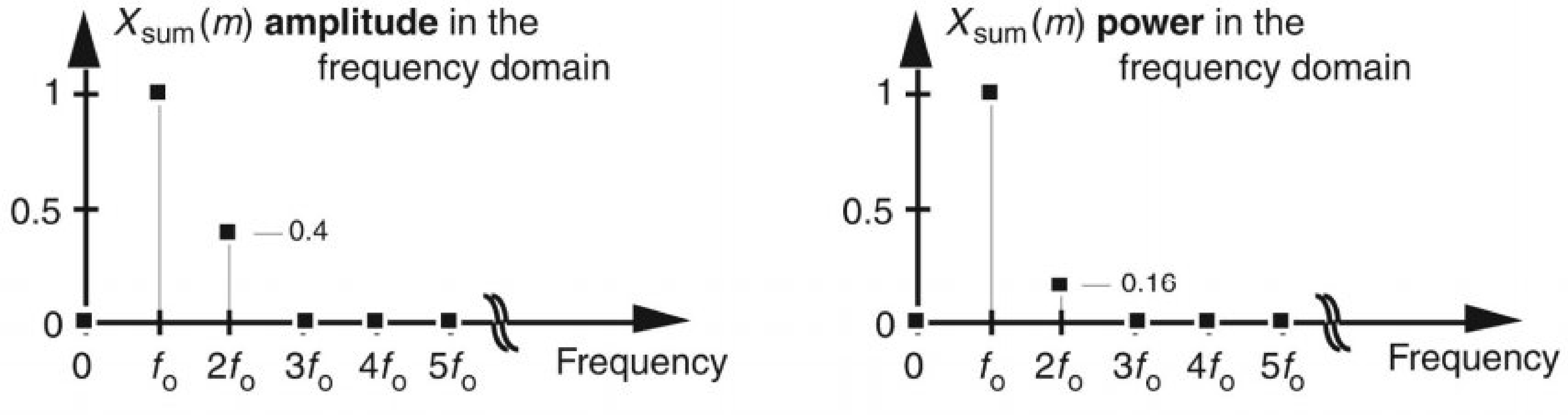

Figure 1–5 Frequency-domain amplitude and frequency-domain power of the $x_{sum}(n)$ time waveform in Figure 1–3(c).

Power is the square of the amplitude, often measured in decibels

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