EE2023 Signals & Systems

Group 1

A/Prof Loh Ai Poh

Office : E2A-04-05
email : elelohap@nus.edu.sg

Classes : Tuesdays & Thursdays
Time : 10am, Venue : E1-06-05

AY2020/21 Semester 2

Outline of Lecture

Textbooks & References

- Douglas K Lindner,*Introduction to Signals and Systems*, McGraw Hill
- Phillips, Parr, Riskin, *Signals, Systems and Transforms*, Pearson, 5th edition
- Hwei Hsu, *Schaum's Outline of Signals and Systems*, McGraw Hill
- Simon Haykin, *An Introduction to Analog and Digital Communications*, John Wiley & Sons, Inc
- Leon W. Couch, II, *Digital and Analog Communication Systems*, Prentice-Hall
- A.V. Oppenheim, A. S. Willsky, *Signals and Systems*, Prentice Hall

I would encourage everyone to download and install Matlab. Matlab is a software that helps you in many computations related to signal processing and systems. Click here for Matlab Set up

There are many Matlab youtube videos to get you started on Matlab.

Assessment Modes

- Closed book quiz (25%) - around week 7, covers materials on Signals
- Take-home Assignment (15%) - week 11, covers materials on Systems
- Final exam (60%) - covers everything

Important Notes

1. Tutorials will be discussed as and when ready. Hence week 1 first lecture/tutorial slot is a lecture slot – not tutorial, so please turn up for both classes in the first week.
2. No labs in this course. The concepts covered here will be re-visited in other lab modules in your higher years – so don't throw away the notes after you are done!
3. Some assignments will be given for practice along the way to strengthen your concepts. You are strongly encouraged to work thru these small assignments.

Syllabus and Topics

First half of semester

1. Signal Representation, Fourier Series and Transform
2. Spectrum of Continuous Time Systems
3. Energy, Power, Bandwidth of Signals
4. Sampling and Signal Reconstruction

Second half of semester

1. Linear Time Invariant (LTI) Systems
2. Notions of Stability : Poles and Zeros
3. Propagation of Signals Thru a LTI System
4. Bode Diagrams : Frequency Response of LTI Systems

Module Learning Outcomes

Signals

1. Describe a signal in time and frequency domains
2. Fourier Series and Fourier Transform and their properties
3. Spectrum of Periodic and Aperiodic Signals
4. Calculate bandwidth, power and energy spectral densities of signals
5. Explain the Nyquist sampling theorem and aliaising

Systems

1. Identify the parameters of linear time invariant (LTI) systems
2. Derive a LTI model using differential equations and transfer functions
3. Compute outputs of LTI systems when driven by step inputs, impulses and sinusoids
4. Evaluate the stability of system through its poles
5. Construct the frequency response of systems using Bode diagrams

Pre-Requisite Knowledge

1. Linear algebra and calculus
2. Complex number ($s = x + jy$) arithmetic, where $j = \sqrt{-1}$, x, y real.
3. Complex functions : $F(s)$ where s is a complex number and $F(.)$ is a function
4. Solutions of first and second order ordinary differential equation
5. Basic circuit theory : Ohms law, Kirchoff circuit laws
6. Some familiarity with Fourier Series / Transform and Laplace Transform

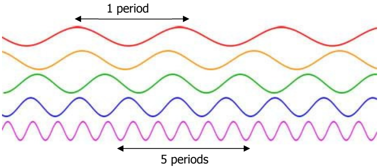
You should have learnt all these from your Math and Engineering Principles and Practice modules.

Terms which you should be familiar with

1. Complex number : $s = x + jy$
   magnitude of $s = |s| = \sqrt{x^2 + y^2}$, Phase of $s =$ $\arg s = \angle s = \tan^{-1}\left(\frac{y}{x}\right)$
2. Complex conjugate : $s = x + jy$, $s^* = x - jy$, where * denotes conjugate. $|s| = |s^*|$, $\arg s = -\arg s^*$ or $\angle s = -\angle s^*$.
3. Exponential functions : examples
   Real exponential function : $x(t) = 3e^{2t}$
   Complex exponential function : $z(t) = 3e^{j2t} = 3\cos(2t) + j\sin(2t)$
4. Sinusoids : $x(t) = 4\sin(2\pi t)$, $y(t) = 5\cos(\pi t)$
5. Frequencies – changing between Hz (usually denoted by f) and radians/sec (usually denoted by ω)
6. Period of a signal and its relationship to frequency (f and ω)
   Period, $T = \frac{1}{f} = \frac{2\pi}{\omega}$
7. Fundamental frequencies as applied to periodic signals

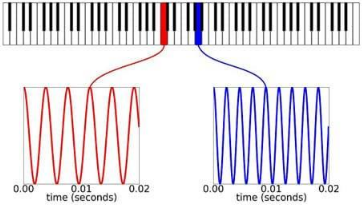
Refer to Revision Notes 0 for more information on complex numbers.

Some Basics about Signals



Signals with different waveforms and frequencies

Each sinusoid has a different period and frequency

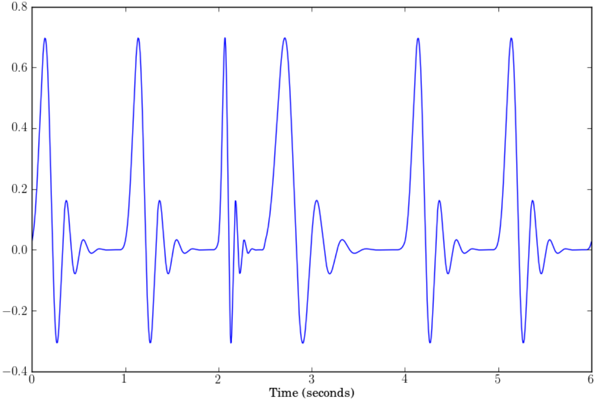


Approx 2.5 cycles in 0.01 sec
250 cycles in 1 sec = 250 Hz
Close to middle C about 260 Hz

Approx 4 cycles in 0.01 sec
400 cycles in 1 sec = 400 Hz
Close to A which is 440 Hz

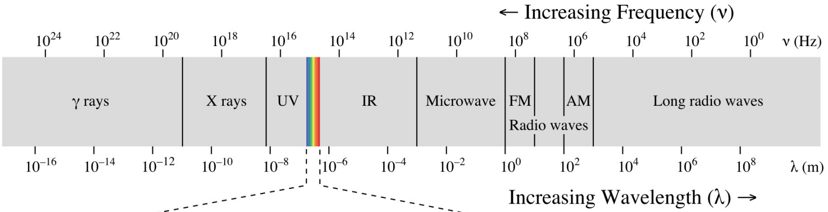
Piano keys which plays sounds of different frequencies

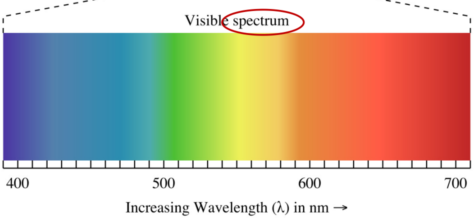
Electrocardiogram (ECG - Signals from the Heart Muscle)

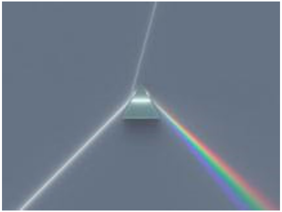


How do we know what frequency components are contained in this signal?
How do we identify all the frequency components that are in this signal?
Leads to the idea of spectrum of a signal.

Spectrum of Electromagnetic Waves







Use of a Prism to Split the Light into its Spectral Components

Why is Signals & Systems important to understand?

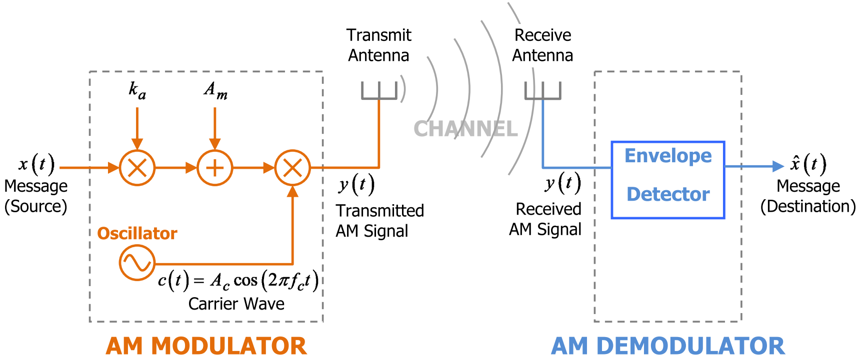
Wide application of signals & systems in the following areas :

1. Communications
2. Signal Processing
3. Modelling and Control

In communications, we often encounter the following :

- Transmissions of signals over a channel
  - Requires modulation & demodulation
  - Analyze spectrum & determine energy/power
- Amplification to boost power levels
- Filtering to remove noise

Example of an Amplitude Modulation (AM) Communications Systems



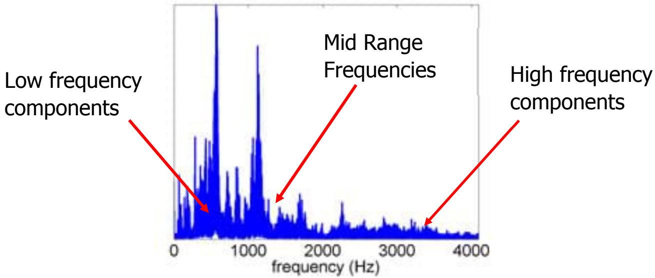
Amplitude modulation is a method of modulation which allows radio signals to be transmitted over the air space. At the receiver, the message signal is recovered by demodulation.

Examples of signal processing which we frequently encounter :

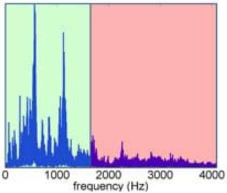
1. Filtering and reconstruction
   - Image processing
   - Audio Processing
2. Bio-signal processing eg EEG, ECG, biometrics (face recognition, fingerprinting)
   - Detect abnormal activity
   - Identity verification
3. Compression for fast, efficient, reliable transmission & data storage
   - Applied to audio, image and video data eg JPEG, MPEG

Example of signal filtering

- All signals are made up of different components with different frequencies
- All signals are inevitably contaminated with noise
- How do we know what are the useful signal components?
- How do we recover the signal components of interest?

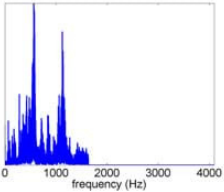


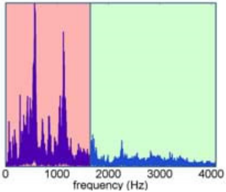
Spectrum of an arbitrary audio signal



Low pass filtered

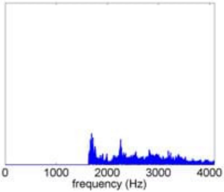
High frequency components removed or filtered, allowing low frequencies to be retained

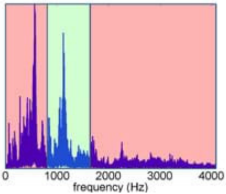




High pass filtered

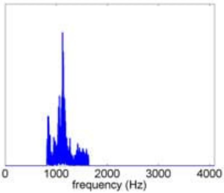
Low frequency components removed or filtered, allowing high frequencies to be retained





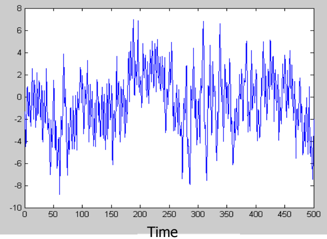
Band pass filtered

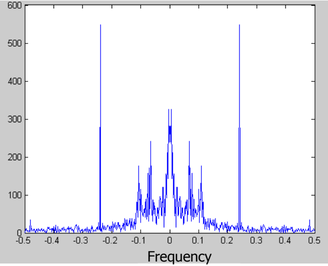
Low and high frequency components removed or filtered, retaining a band of frequencies



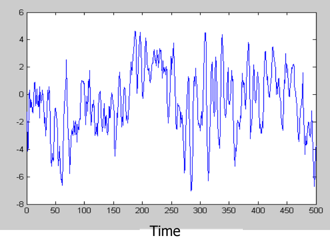
Brain signals are usually contaminated by noise and hard to interpret

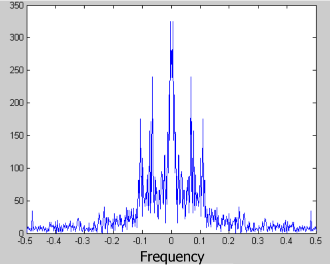
Same signal, different representation





Same signal filtered





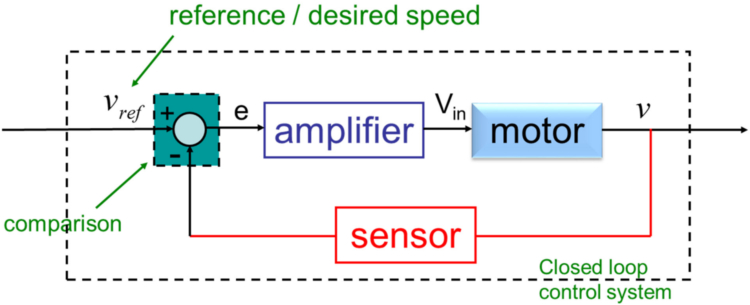
Example of Image (signal) Compression using JPEG

43K Compression 13K 3.5K

JPEG uses a discrete-cosine transform (similar to Fourier Transform) to achieve compression of images

Modelling and control

- Modelling - A model is a mathematical representation of a real physical system. It is used to simulate and predict behaviours
- Control - Examples of control : cruise control in cars, temperature control of rooms, flight control & navigation. Refers to automatic adjustments to achieve tracking of physical variables.



Example of a hard disk drive which requires precise control in the read / write head and spindle motor