Chapter 3

System Modeling in Time and Frequency Domains Part I

Introduction

- In this brief chapter I want to introduce you high level system modeling concepts
- This is a continuation of the communication system block diagrams used in Chapter 1
- To be clear, electronic circuit design needs are motivated by system level requirements, that is a receiver design is required to *perform in such a way*
- At the system level design requirements can be given in terms of *time domain* and *frequency domain* characterizations
- The mathematics of system modeling gets quite complex, but is also very powerful[1]
- In this chapter the math will be very light, mostly pictures
- The idea is to motivate the needs/requirements of particular circuit designs

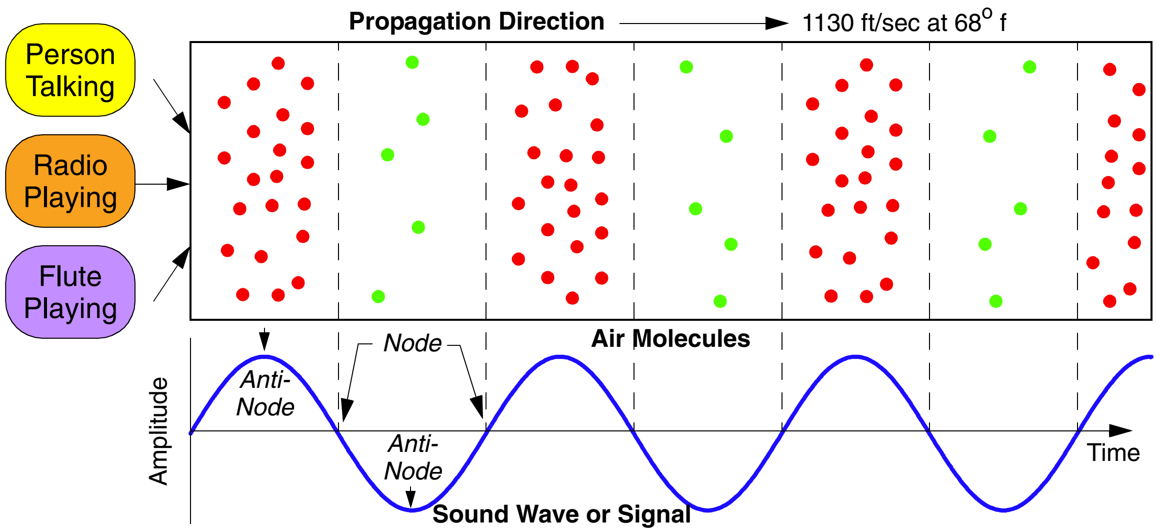
1. M. Wickert, *Signals and Systems for Dummies*, Wiley, 2013.

Signal Modeling

- You are surrounded by signals of various types
  - Some are a part of nature and some man-made
- In this class the focus is communication signals, which are man-made, and which carry information you are interested in
- In an *analog* communications system the underlying information source is an analog *message signal* of interest
  - Typically this is an audible sound signal say corresponding to speech or music
  - Biological signals can be picked up from the body using various sensors, e.g., heart-rate, temperature, blood pressure, respiration rate, etc.
- In a *digital* communication system the underlying information source is digital, meaning it consists of digital data, i.e., 1's and 0's
  - Digital information sources are very common today, computers are everywhere
  - Digital information can be created from an analog source, e.g., streaming audio such as speech and music
  - Sensor signals can be *digitized* and sent over the Internet
- The origin of naturally produced audio signals is mostly sound waves propagating through space
- Sound waves are created when we create a disturbance in the air that creates a *pressure wave*

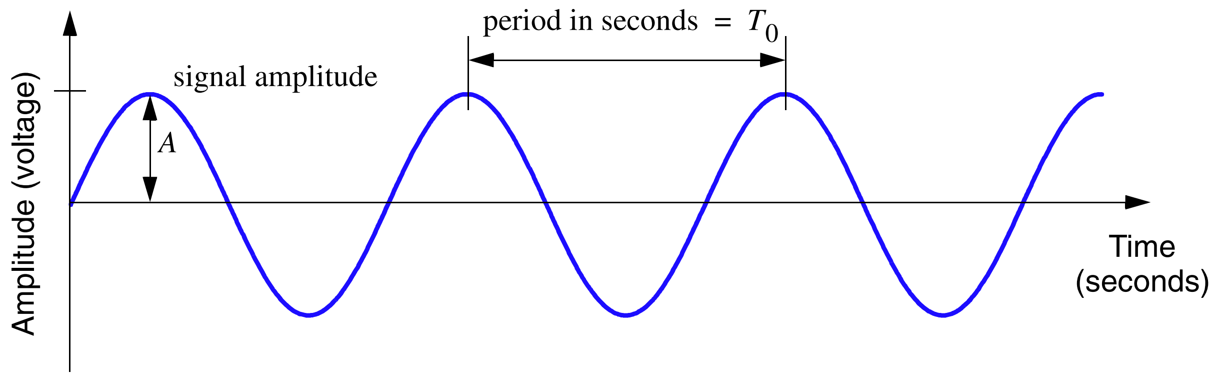
– Sound waves are created by people talking, music from the loud speaker on a radio, a musical instrument playing, the engine on a car, ... many others

- Molecules of air are alternately held at a pressure that is above and below the *normal* or average pressure



Sound Waves as Functions of Time

- If a microphone is place in the path of the sound wave the time changing pressure results in an electrical signal that changes with time
- Similarly if our ear is in the path of the varying pressure of the sound wave, a *nerve signal* is produced and sent to our brain
  - From the electrical signal we can make some basic observations about the sound wave, assuming the wave is *periodic*, or repeats



wavelength (ft) = period (sec) × 1130 ft/sec

frequency = pitch = $f_0 = 1 \div T_0 = \frac{1}{T_0}$

- A very simple, yet also useful mathematical model, $x(t)$, of a sound wave, is a single sinusoid tone

$$x(t) = A\cos[2\pi f_0 t + \phi], -\infty < t < \infty \tag{3.1}$$

  where A is the amplitude, f_0 is the frequency in Hz, and ϕ is the phase shift of the signal

  – For middle A on a keyboard $f_0 = 440\,\text{Hz}$

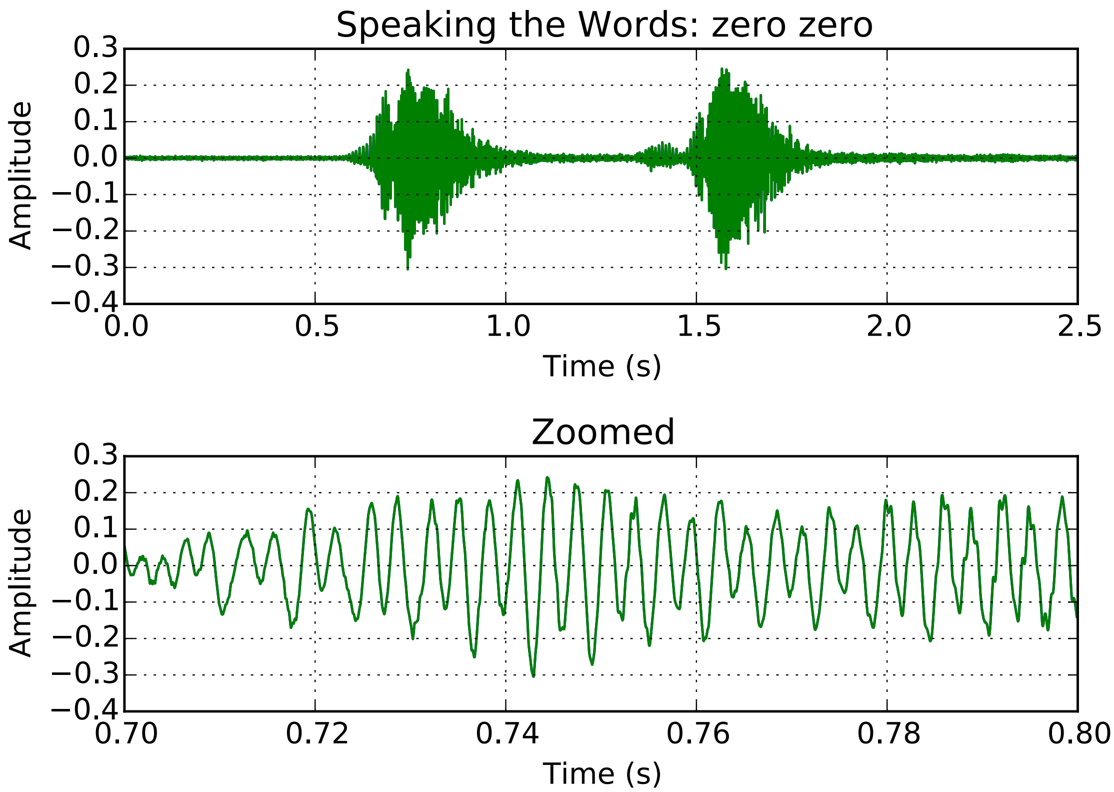
  – **Note**: When a sound pressure wave is picked up by a microphone (sensor) the sound pressure is converted to an electrical signal or waveform

- The waveform view of (3.1) is known as the *time-domain representation*

Example 3.1: A short speech Capture

- I hooked up a microphone to the computer and recorded speaking the words *zero zero*

We can import a .wav file using Python with scipy and sigsys.py



- The speech waveform does not have much of a sinusoidal appearance until you *zoom* in

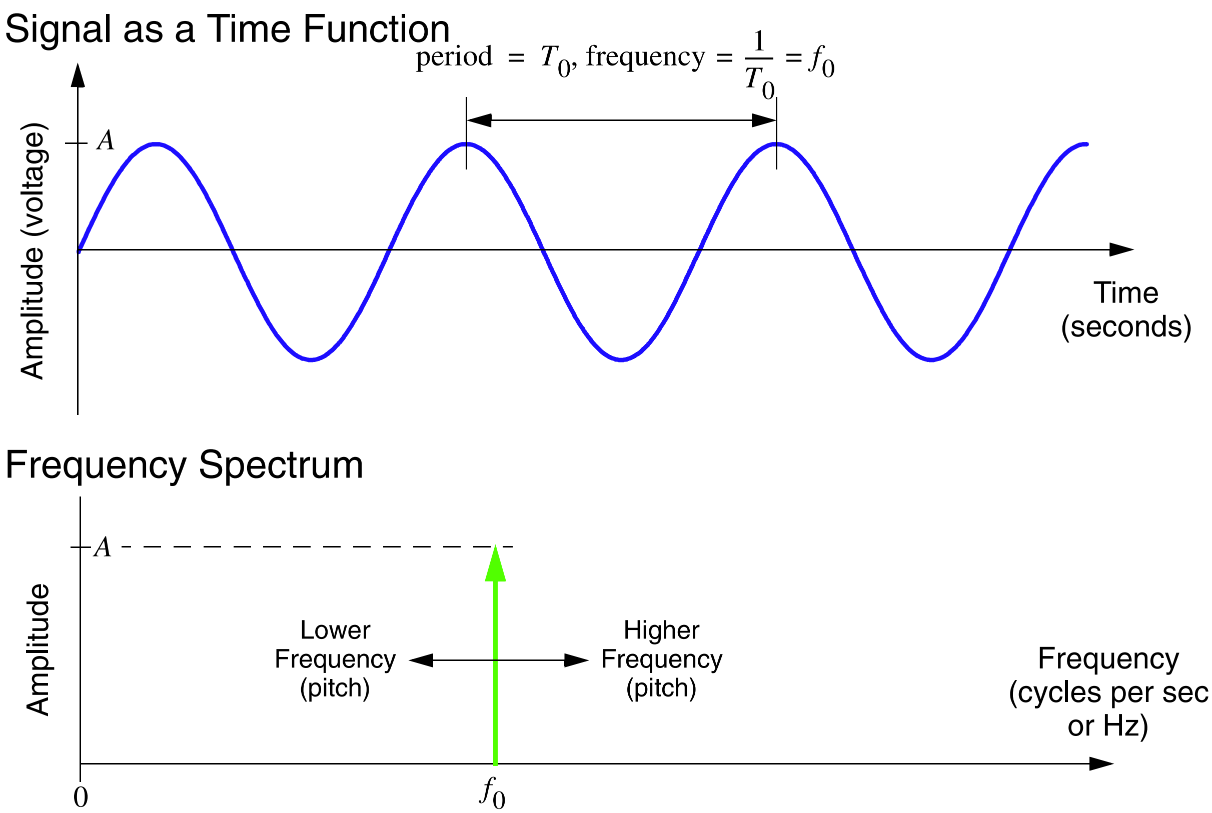
Frequency Spectrum of a Time Signal

- Signals and systems engineers, in particular those in communications, desire an alternative view of signals
- The frequency gives you a distribution of the frequency content found in the time-domain signal
  - For a single sinusoid the spectrum is very compact as there is only a single frequency present
- Formally the Fourier transform of a signal can be used to

obtain its spectrum

– The mathematical details of the Fourier transform lie beyond the scope of this course

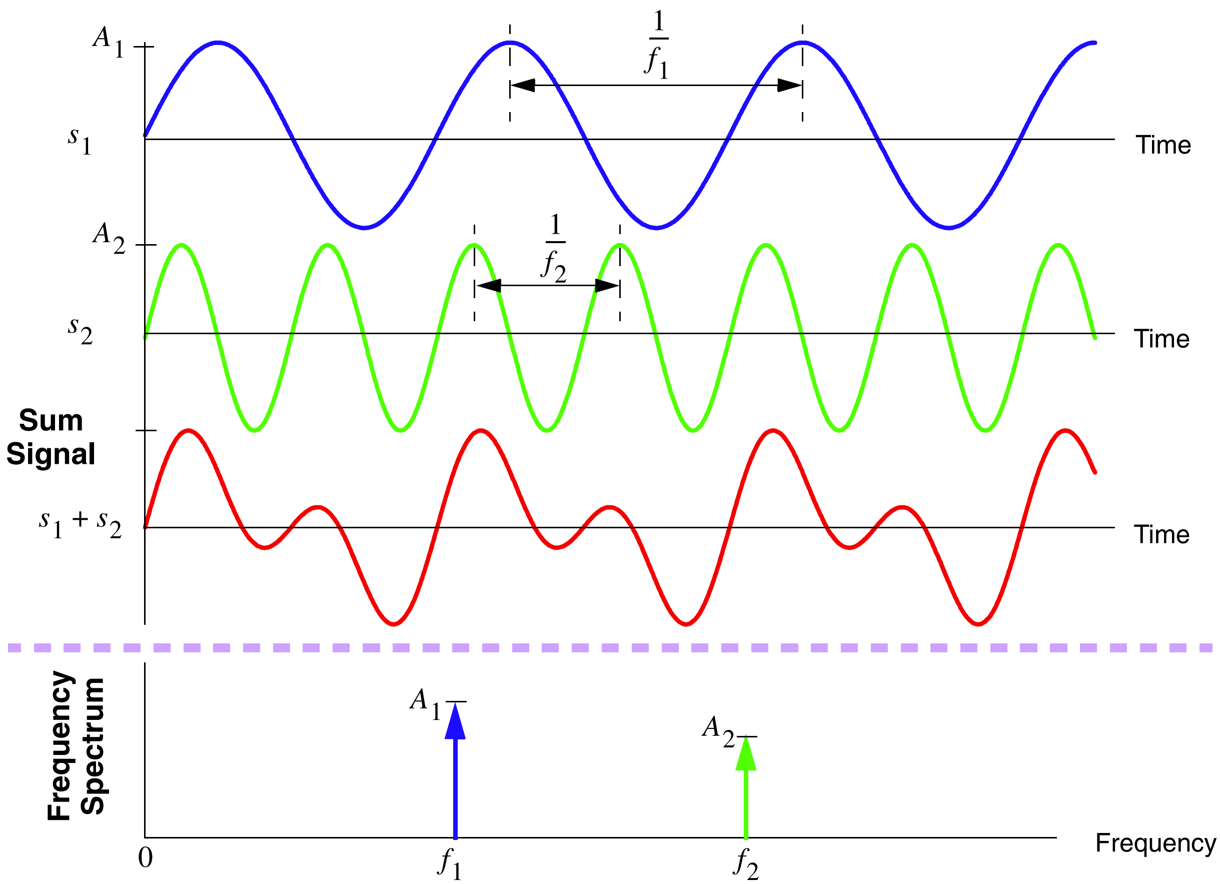
- For the case of a sinusoidal signal you can obtain the spectrum representation as follows:



- Notice how the parameters of amplitude and frequency, present in the original time-domain waveform, appear in the spectrum

– A phase spectrum plot is also possible, but will not be considered here

- Consider the sum of two sinusoid signals at different frequencies



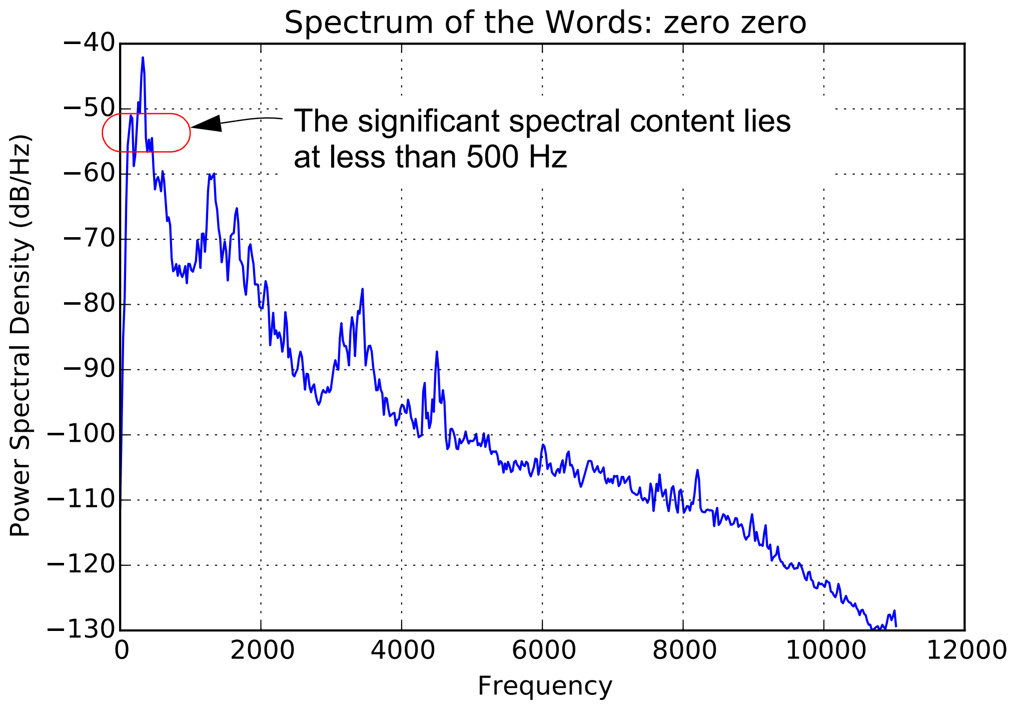
- What do you think? Is you intuition satisfied?
- The spectrum corresponding to superimposed sinusoids consists of two *spectral lines*, one at each of the sinusoid frequencies with spectral height proportional to the original tone amplitudes

---

Example 3.2: Spectrum of Speech Waveform: zero zero

- Again using Python (the *Scipy Stack*) I use the computer to find an estimate of the signal spectrum

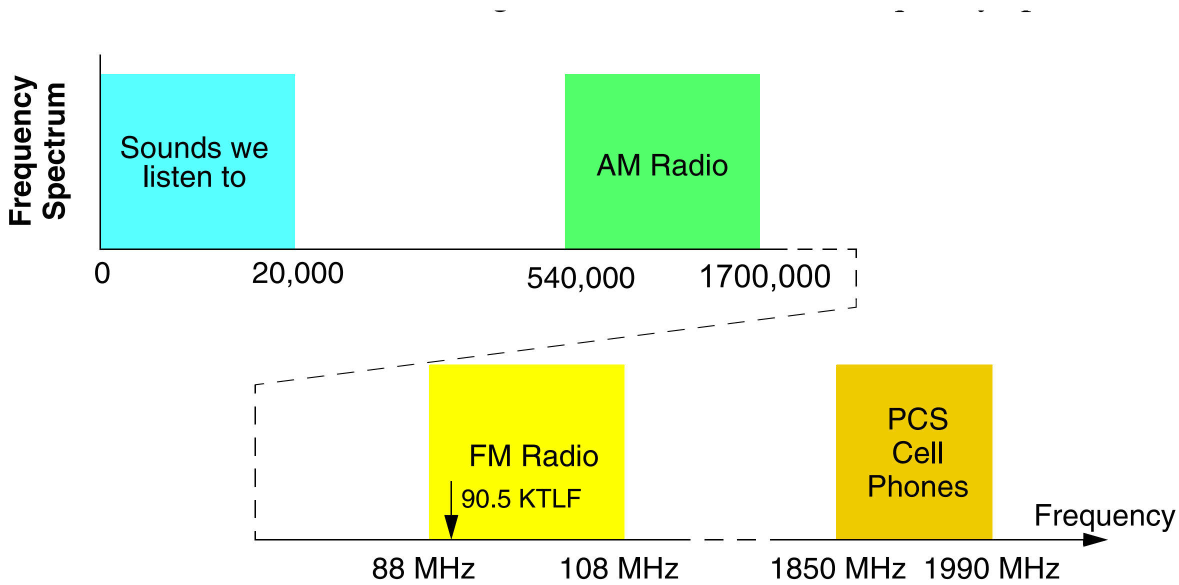
```
In [203]: psd(s[:,1]+s[:,0],2**10,fs);
```



- This signal is not periodic (non-repeating), so you expect to find a lot of different frequencies present in the spectrum

Radio Signals

- When you watch TV or listen to the radio you rely on the reception of waves traveling through the air similar to the way sound waves travel through the air
  - We can again use mathematics to describe radio waves as signals that vary with time, and then view these signals in terms of their frequency spectrum



$$1 \text{ MHz} = 10^6 = 1,000,000 \text{ Hz}$$

- Note in particular that AM radio, which stands for *amplitude modulation*, covers 540 kHz to 1700 kHz
  - With AM the amplitude of the transmitted signal varies in proportion to the message signal
  - In reality AM radio here refers to just commercial AM
  - AM is used in many more applications
- Likewise FM radio, which stands for *frequency modulation*, covers 88 MHz to 108 MHz, is more than just commercial broadcasting
  - With AM the amplitude of the transmitted signal varies in proportion to the message signal
- The mathematics of FM is more complicated than AM
- With both FM and AM transmitted signal is centered on a *carrier frequency*

References

[1] M. Wickert, *Signals and Systems for Dummies*, Wiley, 2013.