Lecture 1-3: Periodic Sounds & Pitch

Overview

1. **Periodic waveforms:** Of the three subjective dimensions of sound: loudness, pitch and timbre, pitch is associated with the 'musical' aspect of the sound. Musical instruments change in pitch to carry a melody, and the intonation of speech is said to be largely implemented through changes in pitch. Only some sounds give a clear sensation of pitch. A generalisation is that sounds with a strong sensation of pitch have **periodic** waveforms, that is they have a waveform pattern with clear cycles that repeat regularly in time. We can measure this periodicity using the time taken to complete one cycle, this is called the **repetition period** and is measured in seconds (s). Alternatively we can calculate how many cycles occur in one second (the reciprocal of the period), which is called the **repetition frequency** and is measured in **hertz** (Hz).
2. **Sensation of pitch**. Our sensation of pitch seems to monotonically related to repetition frequency, but subjectively equal intervals of pitch appear to be logarithmically related to repetition frequency. Musical notation in Western music is based on a logarithmic scale with 12 semitones per octave. One semitone corresponds to an increase of about 6% in repetition frequency, while one octave is a doubling, see Fig 1-3.1.
3. **Simple periodic waveforms:** The simplest periodic waveforms are those that arise from the simplest vibrating systems. The undamped pendulum, tuning fork or mass-on-a-spring vibrate in a simple periodic manner that is called a **sinusoidal waveform** shape, or **sinewave** for short. Sinusoidal waveforms can be completely described with just three parameters: the period (or alternatively the frequency=1/period), the amplitude and the phase (see Fig 1-3.2). The phase of a periodic waveform is a way of measuring how far through its cycle the waveform is at some known time. For a sinusoidal waveform, it is convenient to measure phase in degrees, since a sinewave is also the curve drawn out by the height of a point on the edge of a rotating disc (see Fig 1-3.3). Phase then measures the rotational angle of the disk (usually anti-clockwise from the x-axis). Since sound waves also travel through the air (at the speed of sound), a periodic waveform also gives rise to a periodic pressure variation in space. The length of one cycle in space, called the **wavelength** is just the period times the speed of sound. In air at room temperature, the speed of sound is about $330ms^{-1}$, so a 1000Hz tone with a period of 1ms has a wavelength of 0.33m.
4. **Beats.** When two sinewave sounds of slightly different frequencies are played at the same time, we perceive an effect known as 'beats'. This is caused by the two sinewaves repeatedly going in and out of phase with one another. When they are in-phase, they add to produce a louder sound, when they are out-of-phase, they tend to cancel each other out to produce a quieter sound. Listening for beats can be used to tune musical instruments, since if two tones have the same repetition frequency then beats do not occur.

Reading

Choose at least one from:

- Rosen & Howell, Signals and Systems for Speech and Hearing (1st edition), Introduction to signals pp14-29. *Essentials*.
- Speaks, Introduction to Sound (3rd edition), Chapter 2: Simple harmonic motion. *Thorough but mathematical.*

Learning Activities

You can help yourself understand and remember this week's teaching by doing the following activities before next week:

1. Write down in your own words the difference between periodic and aperiodic sounds, and explain what property of periodic sounds gives rise to our sensation of pitch.
2. Explain how the three parameters of frequency, amplitude and phase uniquely define a sinewave for all time.
3. Research the phenomenon of Beats on the web, and summarise in your own words what it refers to.

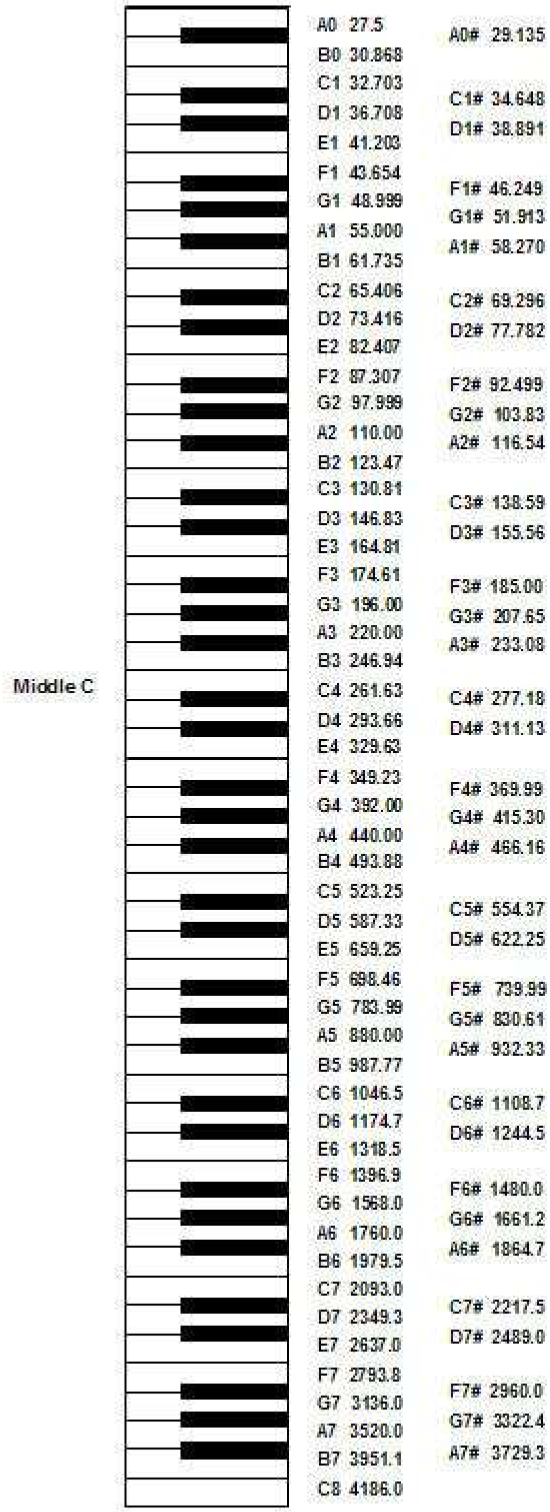
If you are unsure about any of these, make sure you ask questions in the lab or in tutorial.

Reflections

You can improve your learning by reflecting on your understanding. Here are some suggestions for questions related to this week's teaching.

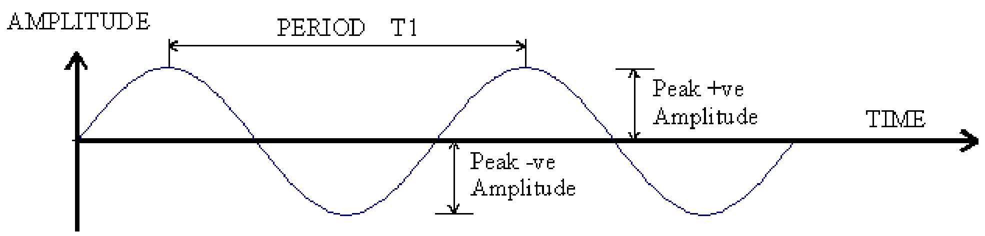
1. What is the difference between pitch and repetition frequency?
2. Think of some ways in which musical instruments produce sounds of different pitches
3. Are the scales of Western music on a linear or logarithmic frequency scale?
4. How do humans produce vowel sounds on different pitches?
5. What is special about sinusoidal waveforms (sinewaves)?
6. What do you need to measure the phase of a sinewave?
7. What is the relationship between repetition period, repetition frequency and wavelength of a periodic sound?

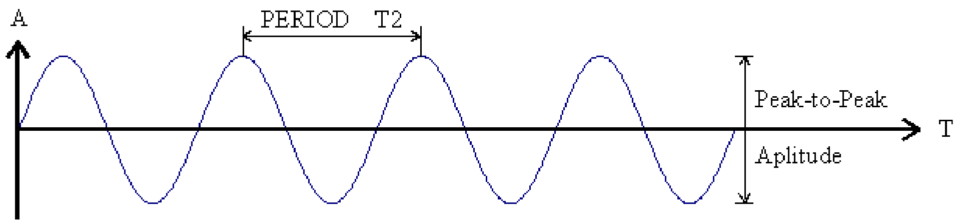
Fig 1-3.1 Piano keyboard showing semitone scale



'Middle C' is called note C4 and has a repetition frequency of 261.63Hz. The C that is one octave higher, C5, has a frequency of 523.25Hz, twice that of C4. The piano has 12 notes in each octave, which divide the octave into 12 equal logarithmic steps called semitones. Each semitone interval corresponds to a change of repetition frequency of ×1.0595.

Fig 1-3.2 Sinusoidal Waveforms





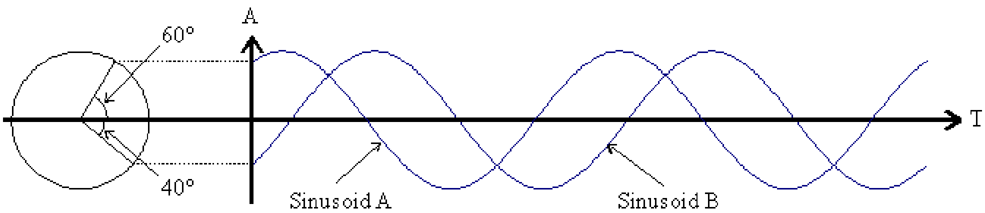
FREQUENCY F1 = 1/T1

PERIOD T2 = T1/2 FREQUENCY F2 = 2.F1

F2 is said to be an **OCTAVE** above F1, because F2 is twice F1.

Fig 1-3.3 Measurement of phase

The delay of a sinusoid can be directly related to **PHASE**.



The height of a point on the edge of a rotating disk traces out a sinusoidal waveform. This leads to a natural definition of **phase** as the angle of the point at some given time.

Sinusoid A has a phase of 60° at time 0.

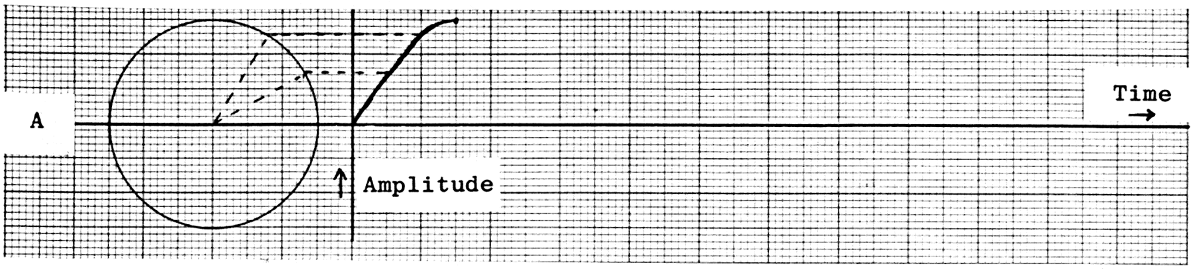
Sinusoid B has a phase of -40° (or +320°) at time 0.

Sinusoid A leads Sinusoid B by 100° : i.e. when B is 0°, A will be 100° (60° – –40°).

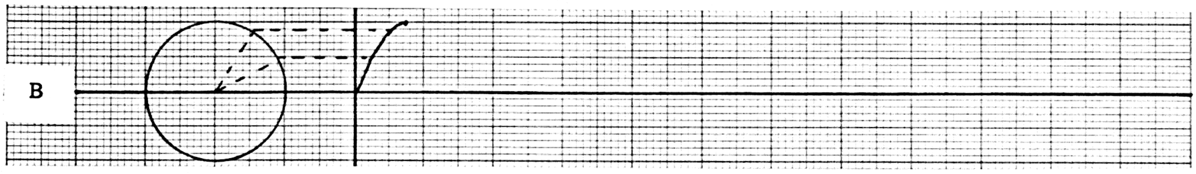
Problem Sheet

1. Construct the following sine waves

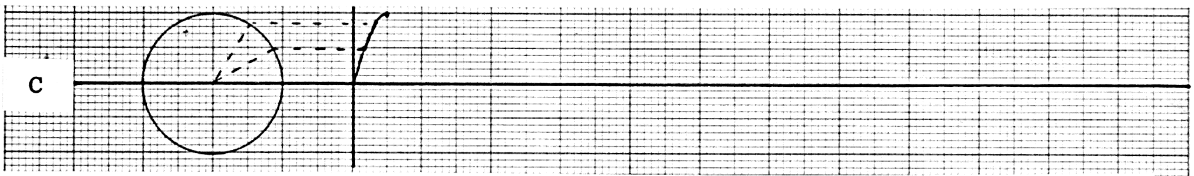
Frequency F — Complete for two cycles



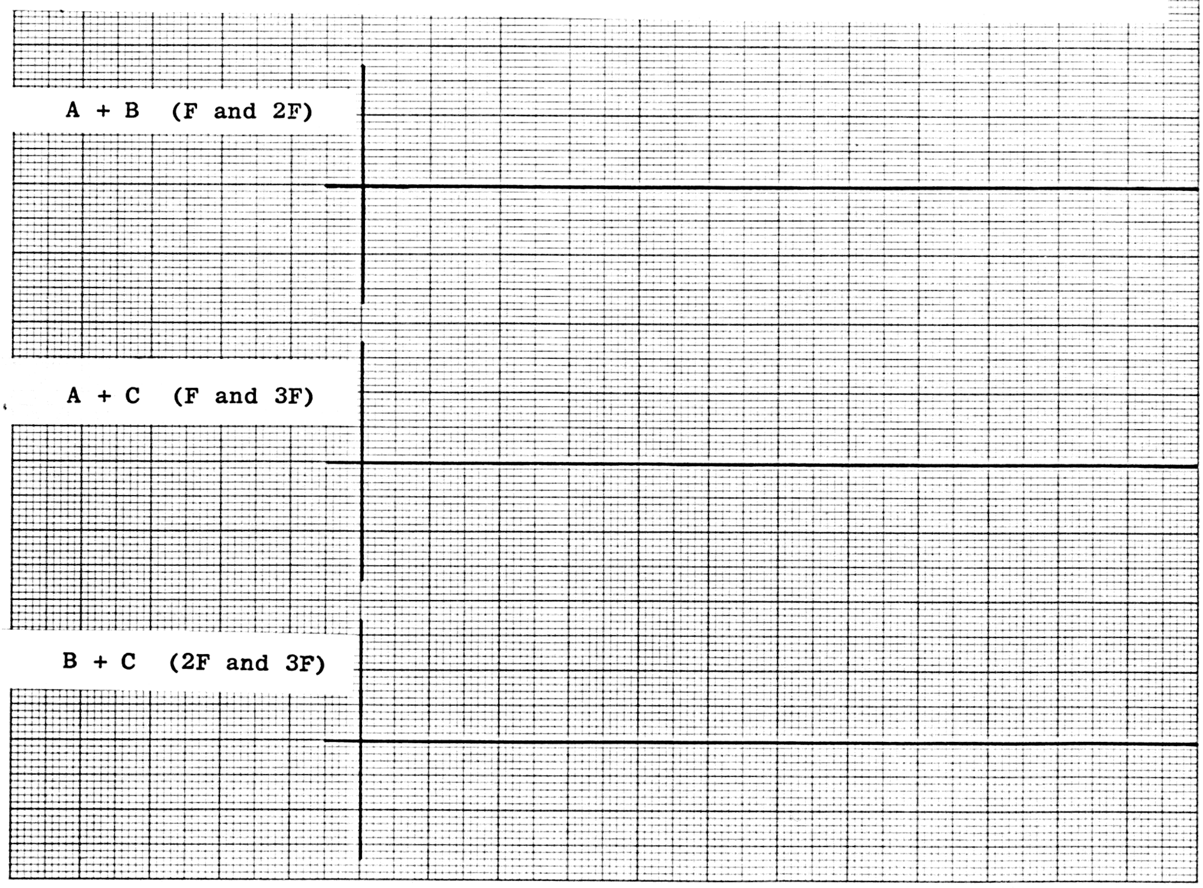
Frequency 2F — Complete for four cycles



Frequency 3F — Complete for six cycles



2. Add the waveforms drawn above in the following combinations
(Take steps of 2 to 5 mm along the time axis)



If you attempt this before the week 1-4 lecture you will understand the concepts better.

Lab 1-3: Pitch Workshop

Introduction

Pitch is one dimension of our perception of sounds. In this lab we explore some aspects of our pitch sensation: firstly the relationship between perceived pitch and the *repetition frequency* of a periodic signal, secondly the phenomenon of beats, thirdly our perceptual preference for logarithmic pitch intervals.

If you are a musician, do bring along a musical instrument to the lab today.

Scientific Objectives

- to make measurements of the repetition frequency of everyday sounds and relate this to our pitch sensation for those sounds
- to explore the linearity of the mapping between pitch and repetition frequency

Learning Objectives

- to understand the difference between pitch and timbre
- to experience the repetition frequencies typical of everyday sounds
- to appreciate the link between Hertz and semitone measurements of repetition frequency

Apparatus

We will use a computer program 'PitchLab' which has been written specially for this lab.

Observations

(a) Repetition frequencies of every day sounds

Use the Pitch Meter to sample some sounds and write down their repetition periods, frequencies and semitone note names:

Sound	Repetition Period (ms)	Repetition Frequency (Hz)	Note name

Here are some suggestions of sounds to try

- □ a vowel sound
- □ a vowel sound on as low a pitch as you can make (be sure to measure a man and woman)
- □ a vowel sound on as high a pitch as you can make
- □ two different vowels on the same pitch
- □ some notes from a musical instrument or pitch pipe
- □ two notes on the same pitch but from different musical instruments
- □ the sound from a tuning fork

Use Fig 1-3.1 to get a sense of where these pitches come on a piano.

(b) Effect of a change in speed on pitch

Use the Speed Changer to record some sounds and play them back faster and slower than normal. Note that the speed changer control is effectively a multiplier on the repetition frequency. So a sound with a repetition frequency of 110Hz when played back with the speed changer set to 2.0 would replay the sound with a repetition frequency of 220Hz.

A change of 0.94 or 1.06 will give you a change of one semitone.
A change of 0.50 or 2.00 will give you a change of one octave

Record a short vowel. What is the smallest speed change you can hear?
When you change the speed of a spoken sentence, what happens to the sound apart from the change in pitch?

(c) Perception of Beats

Use the Beats tab to generate a sound by adding two sinewaves together. Try different pairs of frequencies to try and find an explanation for the waveform shape and sound that you obtain. The waveform displayed is exactly one second long.

Here are some suggestions for pairs of frequencies to get started:

Frequency 1 (Hz)	Frequency 2 (Hz)	Beat Frequency (Hz)
1000	1010	
1000	1005	
1000	1002	
500	510	
500	505	
Etc		

Can you find a formula to predict the third column from the first two?
Why do you think we hear beats as a new sound quality?

(d) Measuring subjective Pitch intervals

Use the Pitch Perception tab to explore how human listeners divide a pitch interval into two subjectively equal halves. Given two repetition frequencies like 100 and 400, do subjects find the "middle" at the arithmetic mean (250Hz) or at the logarithmic mean (200Hz)?

Have one person present tones to a second person listening on headphones, and ask them to say whether the middle tone should go higher or lower to make the middle tone 'half-way', i.e. such that the two pitch steps are subjectively equal. Write down the preferred value and compare with the predictions from the arithmetic mean and the logarithmic mean

Here are some suggested pitches to try:

Low (Hz)	High (Hz)	Arithmetic Mean (Hz)	Logarithmic Mean (Hz)	Preferred mid-point (Hz)
250	1000			
250	750			
250	500			
250	375			
500	2000			
500	1000			
etc	etc			

What do you conclude from these results about how we perceive pitch intervals?
How might you test whether one method of prediction was better than the other?

Concluding Remarks

1. In pitch terms, what is the difference between talking and singing?
2. Find out what repetition frequency ratios correspond to the musical terms "a perfect fifth" and "a major third".