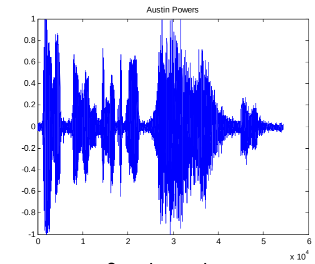
- Previous Lecture:
  - Working with sound files
- Today's Lecture:
  - Frequency computation
  - Touchtone phone
- Announcement:
  - Section in the computer lab this week
  - Prelim 3 tonight 7:30-9pm
    - A-F in Kimball B11
    - G-L Ives 305
    - M-R in Upson B17
    - S-Z in Olin 255

We looked at the time domain last lecture

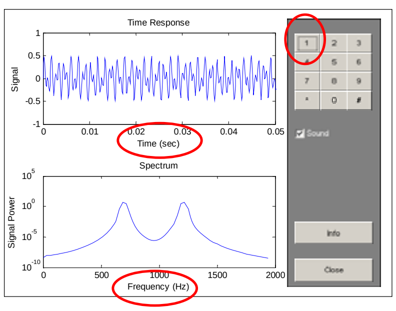


Sample number

Time

What about the frequency domain?

>> phone

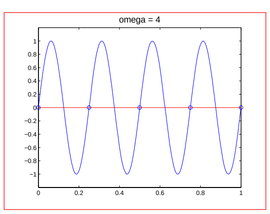


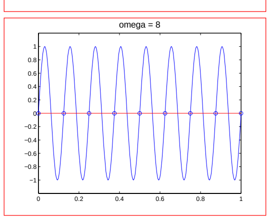
A "pure-tone" sound is a sinusoidal function

$$y(t) = \sin(2\pi\omega t)$$

ω = the frequency

Higher frequency means that y(t) changes more rapidly with time.





Still looking at the time domain

$$y(t) = \sin(2\pi \cdot 4t)$$

$$y(t) = \sin(2\pi \cdot 8t)$$

Digitize for Graphics

```
% Sample "Rate"
  n = 200
% Sample times
  tFinal = 1;
  t = 0:(1/n):tFinal
% Digitized Plot…
  omega = 8;
  y= sin(2*pi*omega*t)
  plot(t,y)
```

Digitize for Sound

```
% Sample Rate
  Fs = 32768
% Sample times
  tFinal = 1;
  t = 0:(1/Fs):tFinal
% Digitized sound…
  omega = 800;
  y= sin(2*pi*omega*t);
  sound(y,Fs)
```

Equal-Tempered Tuning

0 A	55.00	110.00	220.00	440.00	880.00	1760.00
1 A#	58.27	116.54	233.08	466.16	932.33	1864.66
2 B	61.74	123.47	246.94	493.88	987.77	1975.53
3 C	65.41	130.81	261.63	523.25	1046.50	2093.01
4 C#	69.30	138.59	277.18	554.37	1108.73	2217.46
5 D	73.42	146.83	293.67	587.33	1174.66	2349.32
6 D#	77.78	155.56	311.13	622.25	1244.51	2489.02
7 E	82.41	164.81	329.63	659.26	1318.51	2637.02
8 F	87.31	174.61	349.23	698.46	1396.91	2793.83
9 F#	92.50	185.00	369.99	739.99	1479.98	2959.95
10 G	98.00	196.00	391.99	783.99	1567.98	3135.96
11 G#	103.83	207.65	415.31	830.61	1661.22	3322.44
12 A	110.00	220.00	440.00	880.00	1760.00	3520.00

Entries are frequencies. Each column is an octave.
Magic factor = 2^(1/12). C3 = 261.63, A4 = 440.00

April 15, 2008 Lecture 23 7

`playTwoNotes.m`

April 15, 2008 Lecture 23 8

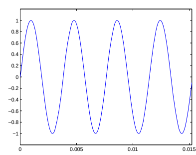
Adding Sinusoids

```
Fs = 32768; tFinal = 1;
t  = 0:(1/Fs):tFinal;

C3  = 261.62;
yC3 = sin(2*pi*C3*t);
A4  = 440.00;
yA4 = sin(2*pi*A4*t);
y   = (yC3 + yA4)/2;

sound(y,Fs)
```

April 15, 2008 Lecture 23 9

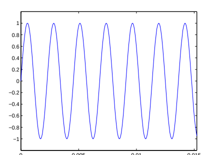
Adding Sinusoids

C3:



+

A4:



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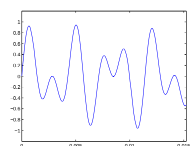


April 15, 2008 Lecture 23 10

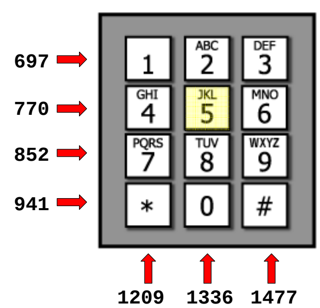
Application: touchtone telephones

Make a signal by combining two sinusoids

April 15, 2008 Lecture 23 11

A frequency is associated with each row & column.

So two frequencies are associated with each button.



"5"-Button corresponds to (770,1336)

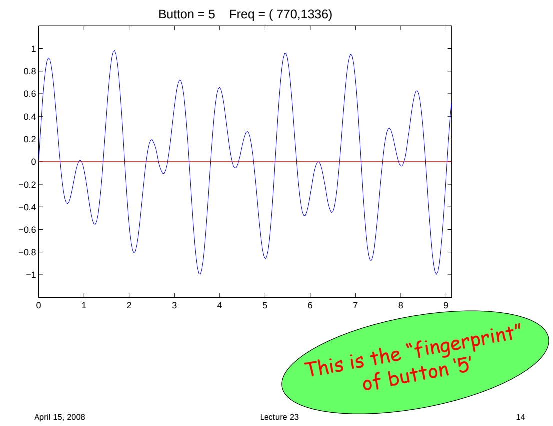
Each button has its own 2-frequency "fingerprint"!

Signal for button 5:

```
Fs = 32768;
tFinal = .25;
t  = 0:(1/Fs):tFinal;

yR = sin(2*pi*770*t);
yC = sin(2*pi*1336*t)
y  = (yR + yC)/2;

sound(y,Fs)
```

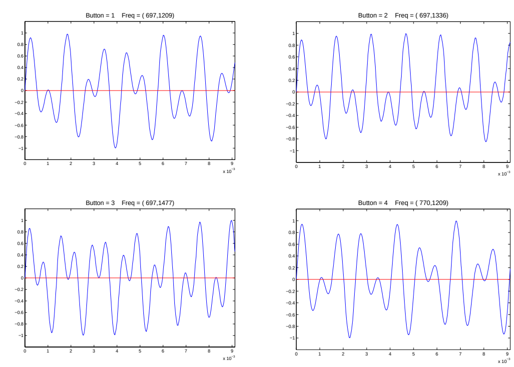
To Minimize Ambiguity…

No frequency is a multiple of another.

The difference between any two frequencies does not equal any of the frequencies.

The sum of any two frequencies does not equal any of the frequencies.

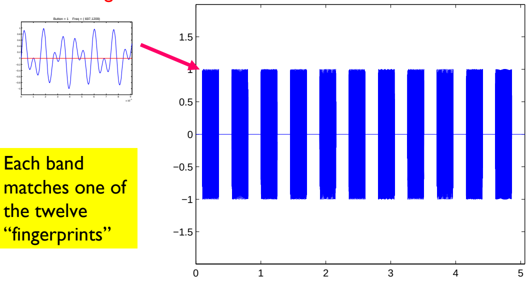
The sinusoids for buttons 1,2,3, and 4



playPhoneButtons.m

What does the signal look like for a multi-digit call?

"Perfect" signal

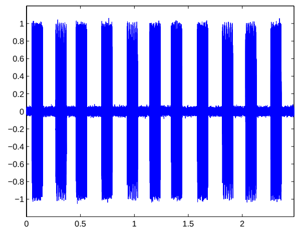


Each band matches one of the twelve "fingerprints"

Buttons pushed at equal time intervals

"Noisy" signal

Each band approximately matches one of the twelve "fingerprints." There is noise between the button pushes.



Buttons pushed at unequal time intervals

The Segmentation Problem

When does a band begin?

When does a band end?

Somewhat like the problem of finding an edge in a digitized picture.

April 15, 2008 Lecture 23 20

Fourier Analysis

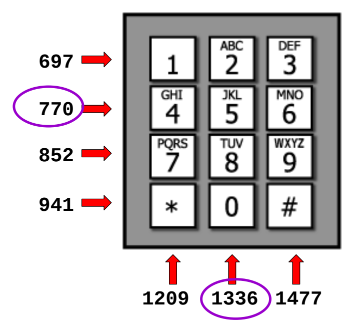
Once a band is isolated, we know it is the sum of two sinusoids:

What are the two frequencies?

Use Fourier analysis to find out.

April 15, 2008 Lecture 23 21

Remember that knowing the two frequencies means knowing which button was pushed



Ah-ah! Button 5 was pushed.

```
makeCall.m
findNumber.m
showFindNumber.m
```

April 15, 2008 Lecture 23 23