L26. More on Sound File Processing

Frequency Computations
Touchtone Phones

Let's Understand Frequency

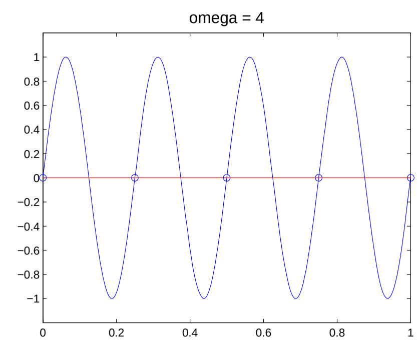
A Sinusoidal Function

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

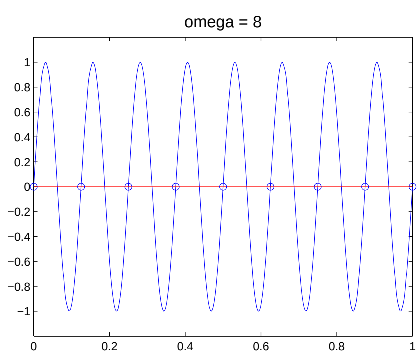
ω = the frequency

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

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



$$y(t) = \sin(16\pi t)$$



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)
```

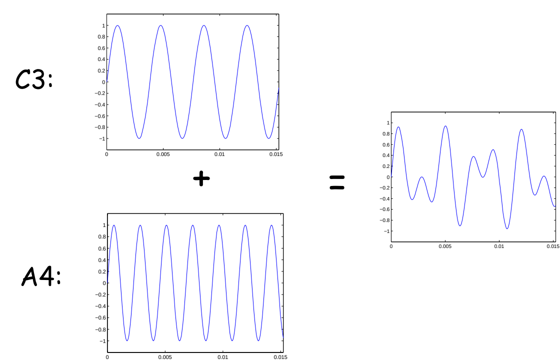
Equal-Tempered Tuning

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

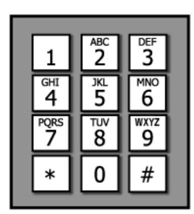
Adding Sinusoids

```
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)
```

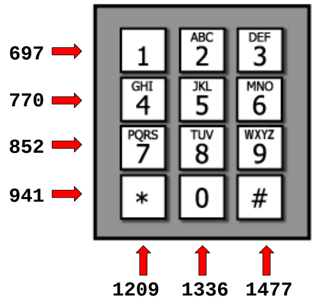


Application: Touchtone Telephones

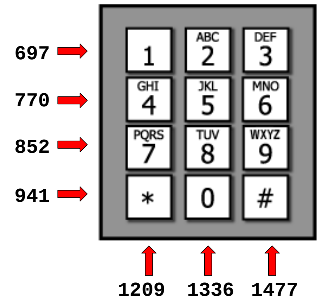
Let's Make a Signal By Combining Two Sinusoids



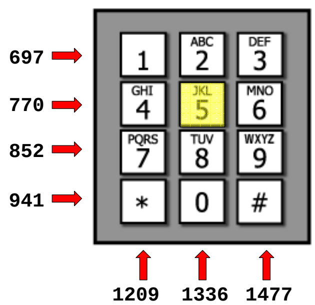
A Frequency Is Associated With Each Row & Column



A Frequency Is Associated With Each Row & Column



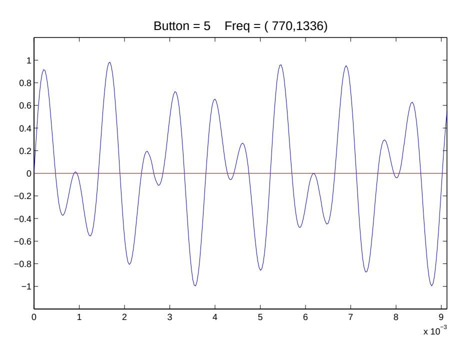
Two Frequencies Are Associated With Each Button



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

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)
```



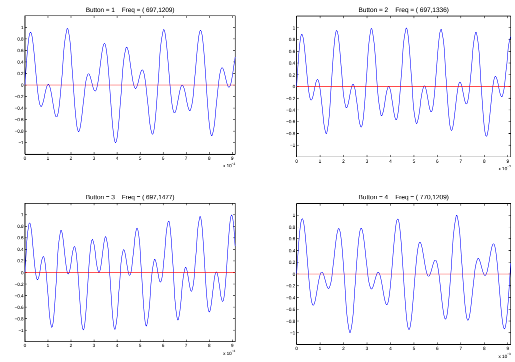
Each Button Has Its Own Two-Frequency "Fingerprint"

To Minimize Ambiguity…

No frequency is a multiple of another

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

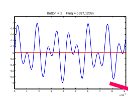
The sum of any two frequencies does not equal any of the frequencies.



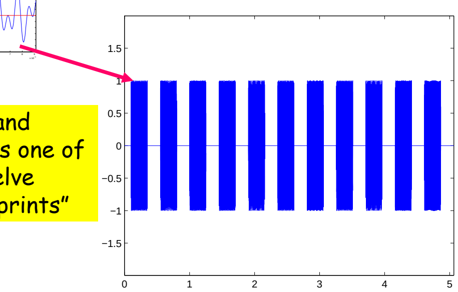
The Sinusoids for Buttons 1,2,3, and 4

What Does the Signal Look Like For a Multi-Digit Call?

"Perfect" Signal



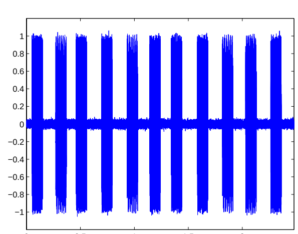
Each band matches one of the twelve "fingerprints"



Buttons Pushed at Equal Time Intervals

"Noisy" Signal

Each band approximately matches one of the twelve "fingerprints"



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.

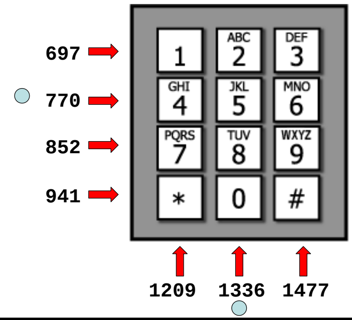
Fourier Analysis

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

What are the two frequencies?

Fourier analysis tells you.

Knowing the Two Frequencies Means We KnowThe Button



Ah-ah! Button 5 was pushed.