- Previous Lecture:
  - Working with sound files
- Today's Lecture:
  - Frequency computation
  - Touchtone phone
- Announcement:
  - Discussion in the computer lab this week. Bring headphones.
  - Prelim 3 tonight at 7:30pm, Statler Auditorium
    - Lastnames A-O: main seating area
    - Lastnames P-Z: balcony
  - No consulting tonight 7-10pm

Example: playlist

Suppose we have a set of .wav files, e.g.,

```
austin.wav
sp_beam.wav
sp_oz6.wav
```

and wish to play them in succession.

Possible solution

```
playList = {'austin',…
           'sp_beam',…
           'sp_oz6'};

for k=1:length(playList)
   [y,rate] = wavread(playList{k});
   sound(y,rate)
end
```

Store the data from wav files as a struct array for play back later

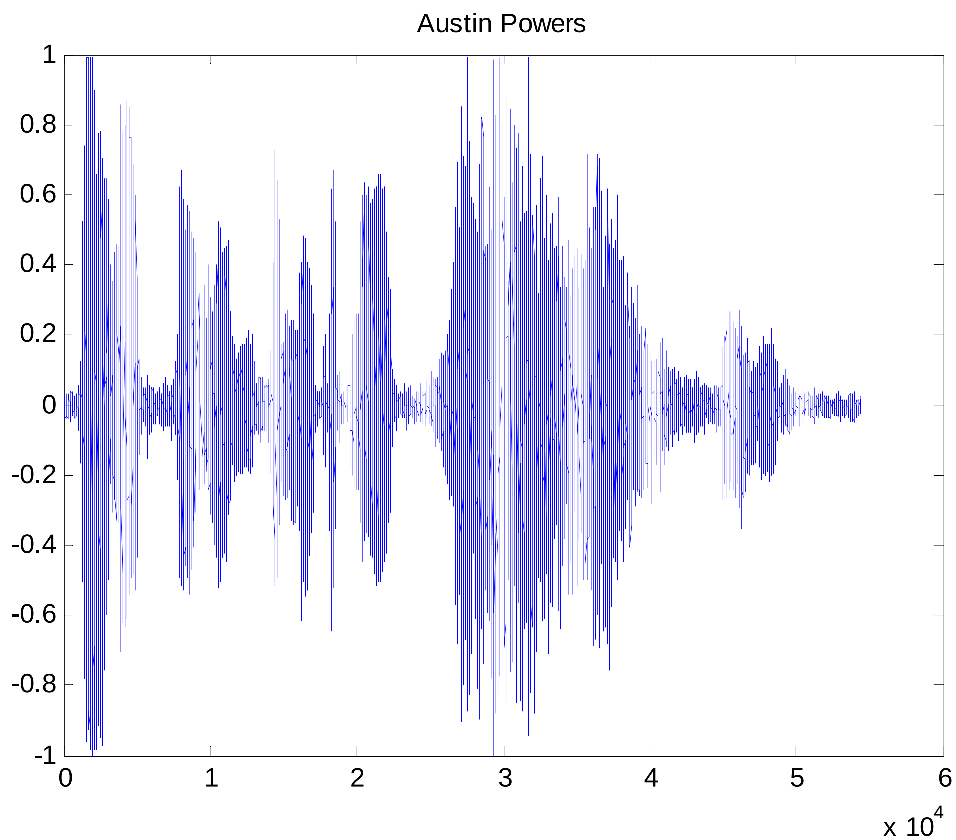
```
function SA = wavSegments(wnames)
% Build a struct array SA such that
%   SA(k).data  stores the data of wnames{k}
%   SA(k).rate  stores the sampling rate of
%               wav file wnames{k}

for k= 1:length(wnames)
   [y,rate] = wavread(wnames{k});
   SA(k)= struct('data', y, 'rate', rate);
end
```

```
function playSegments(SA)
% Play sound data stored in struct array SA.
%   SA(k).data  stores the k-th segment of
%               sound data (from wavread)
%   SA(k).rate  is sampling rate of k-th seg.

for k= 1:length(SA)
    theData= SA(k).data;
    theRate= SA(k).rate;
    sound(theData,theRate)
end
```

Next call to sound will not begin until after the previous call is complete.

Not true in older versions! Calculate and add your own pause in that case.

We looked at the time domain

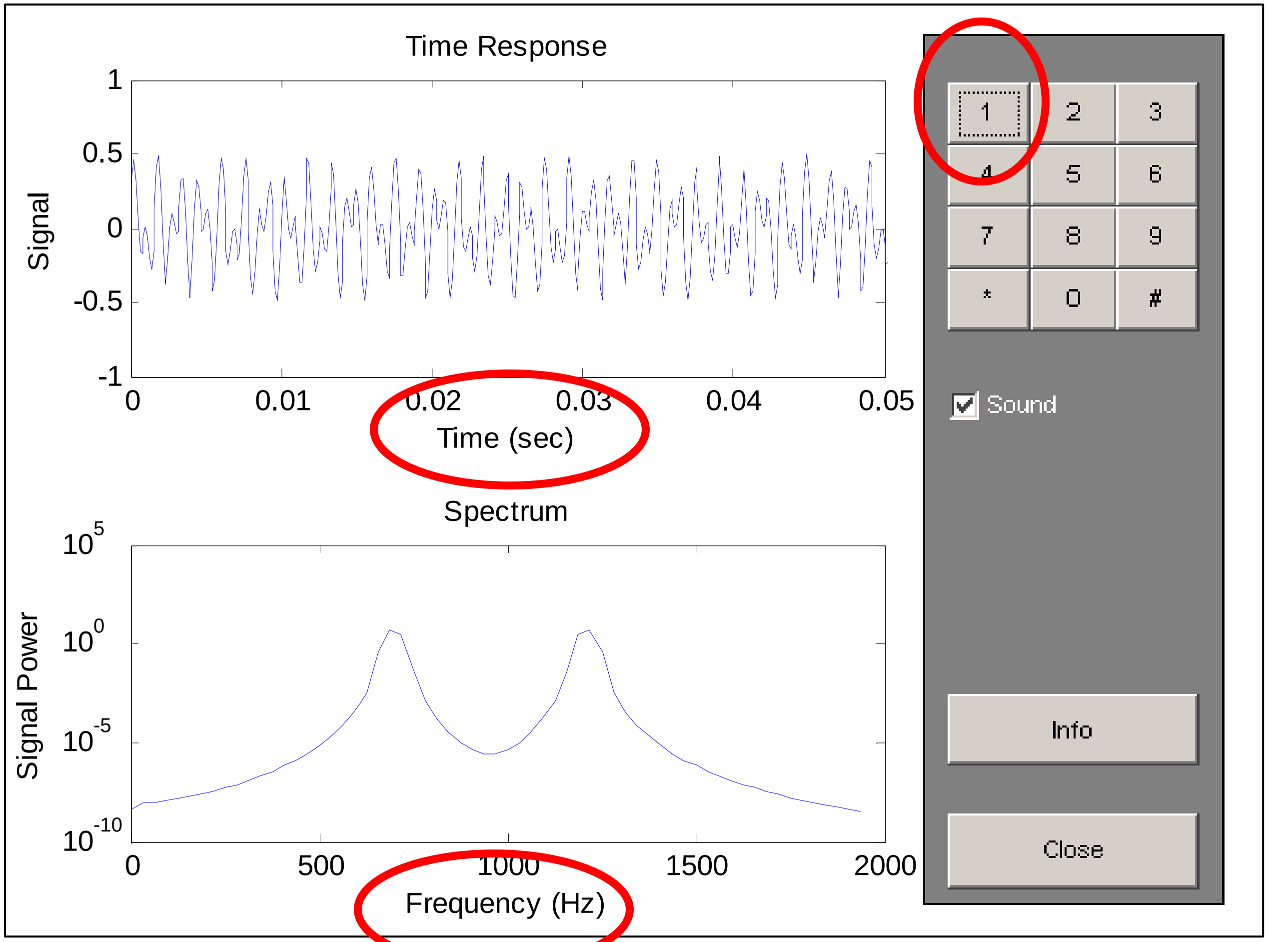


Sample number

Time

What about the frequency domain?

>> phone



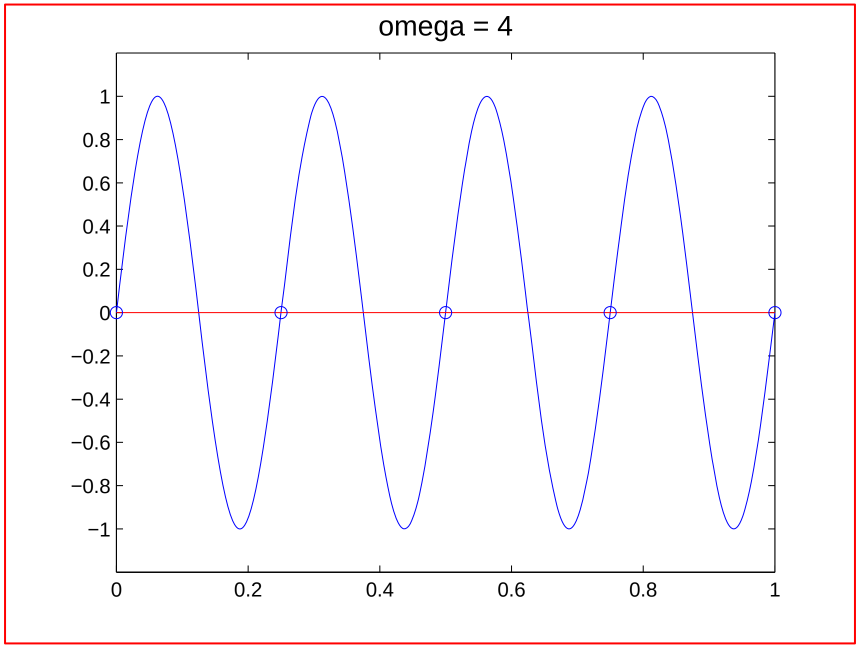
A “pure-tone” sound is a sinusoidal function

$$y(t) = \sin(2\pi\underline{\omega}t)$$

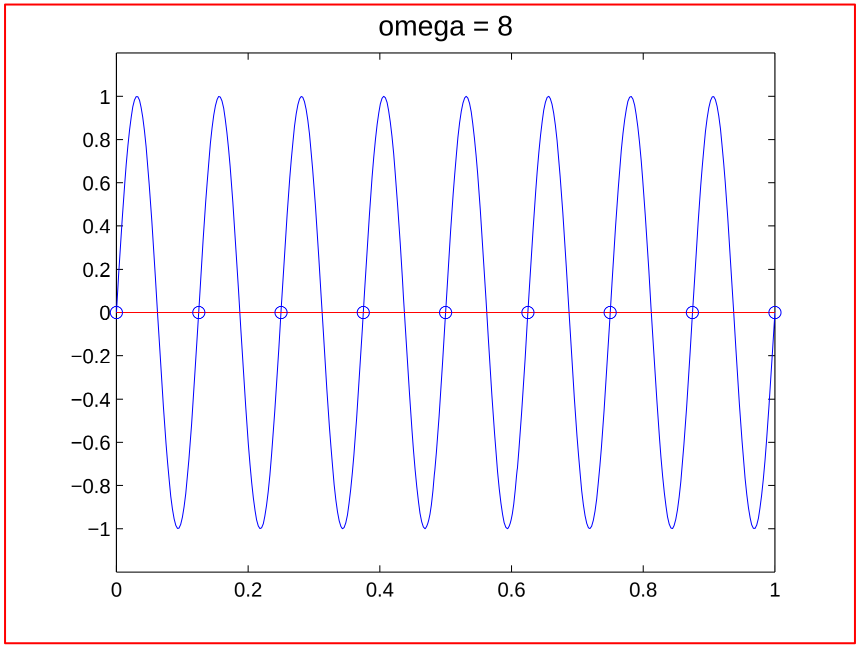
$\underline{\omega}$ = the frequency

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

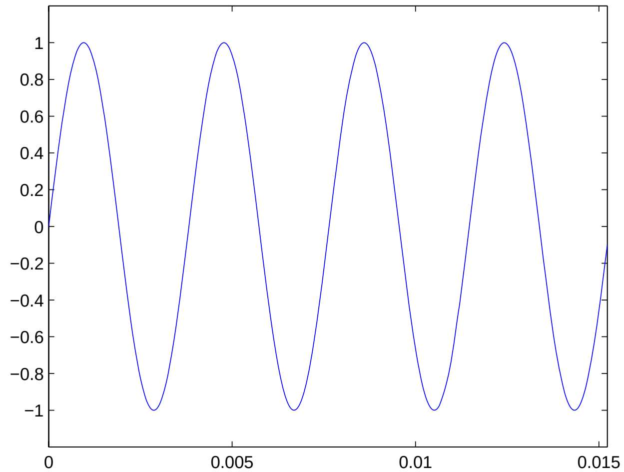
0 A	55.00	110.00	220.00	440.00	880.00	1760.00
1 A#	58.27	116.54	233.08	466.16	932.33	1864.66
2 B	61.74	123.47	246.94	493.88	987.77	1975.53
3 C	65.41	130.81	261.63	523.25	1046.50	2093.01
4 C#	69.30	138.59	277.18	554.37	1108.73	2217.46
5 D	73.42	146.83	293.67	587.33	1174.66	2349.32
6 D#	77.78	155.56	311.13	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

“Adding” Sinusoids

Middle C:

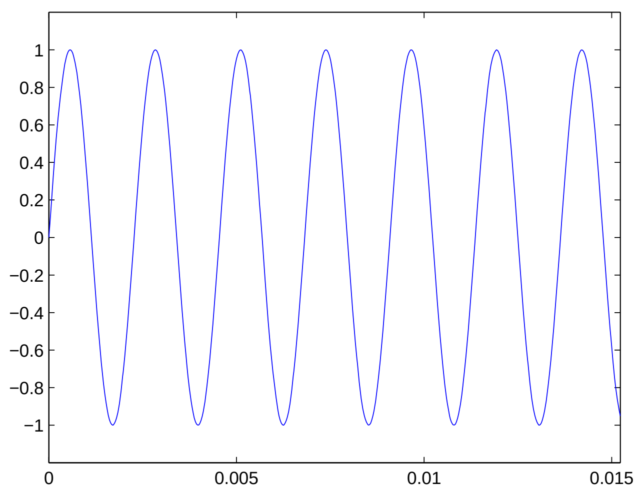
$$\omega = 262$$



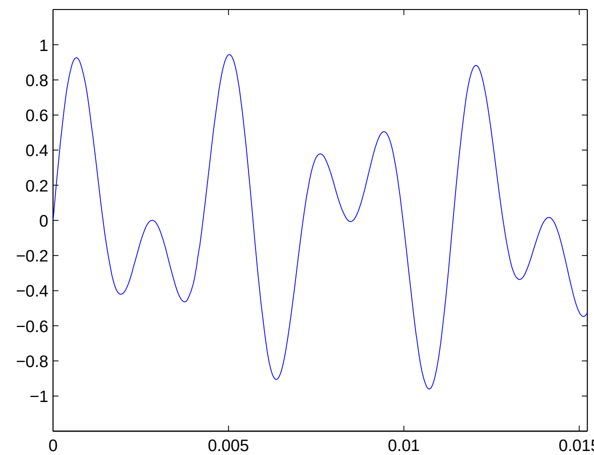
+

A above middle C:

$$\omega = 440$$



=



`playTwoNotes.m`

“Adding” Sinusoids → *averaging* the sine values

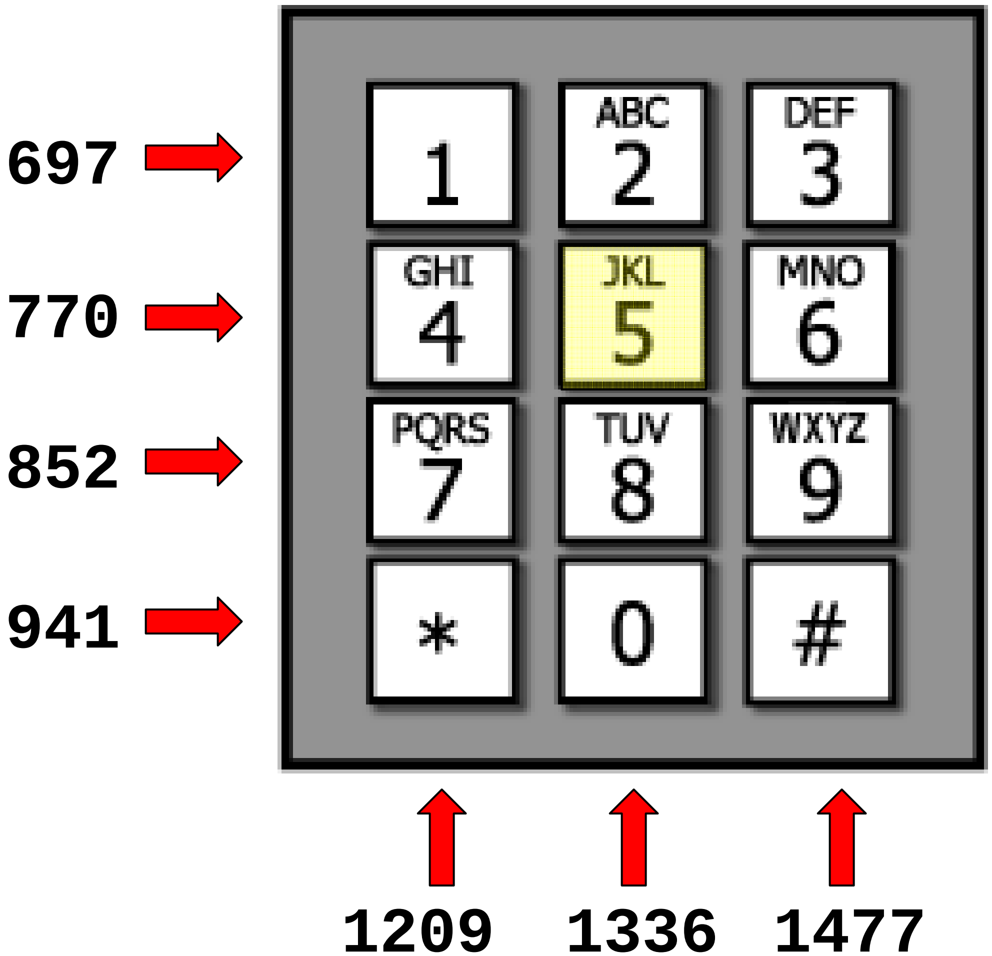
```
Fs = 32768; tFinal = 1;
t  = 0:(1/Fs):tFinal;

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

Make a signal by combining two sinusoids

A frequency is associated with each row & column.

So two frequencies are associated with each button.



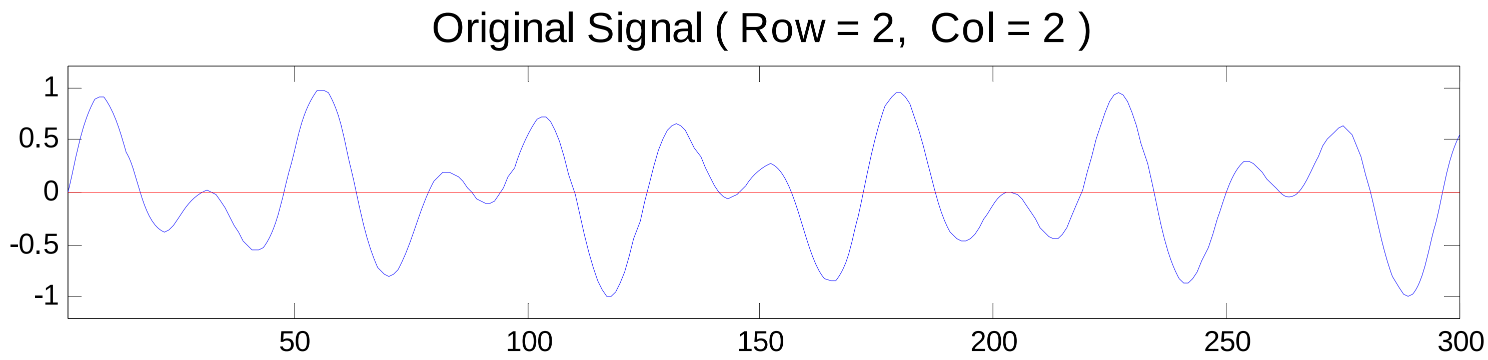
The "5"-Button corresponds to (770,1336)

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)
```

MakeShowPlay.m



This is the "fingerprint" of button '5'

`playAllButtons.m`

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

Why is this important?

I dial a number (send signal). The receiver of the signals get a "noisy" version of the real signal. How will the noisy data be interpreted?

`SendNoisy.m`

How to compare two signals (vectors)?

Given two vectors x and y of the same length, the cosine of the angle between the two vectors is a measure of the correlation between vectors x and y:

$$\cos_{xy} = \frac{\left|\sum_{i=1}^{n} x_i y_i\right|}{\sqrt{\sum_{i=1}^{n} x_i^2} \cdot \sqrt{\sum_{i=1}^{n} y_i^2}}$$

Small cosine → low correlation

High cosine → highly correlated

How to compare two signals (vectors)?

Given two vectors x and y of the same length, the cosine of the angle between the two vectors is a measure of the correlation between vectors x and y:

$$\cos_{xy} = \frac{\left| \sum_{i=1}^{n} x_i y_i \right|}{\sqrt{\sum_{i=1}^{n} x_i^2} \cdot \sqrt{\sum_{i=1}^{n} y_i^2}}$$

Small cosine → low correlation

High cosine → highly correlated

`cos_xy.m`

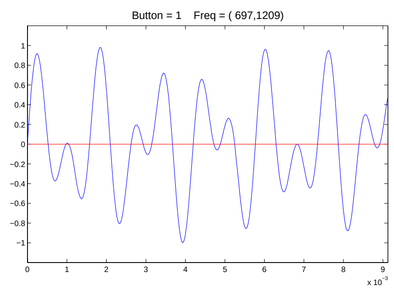
`ShowCosines.m`

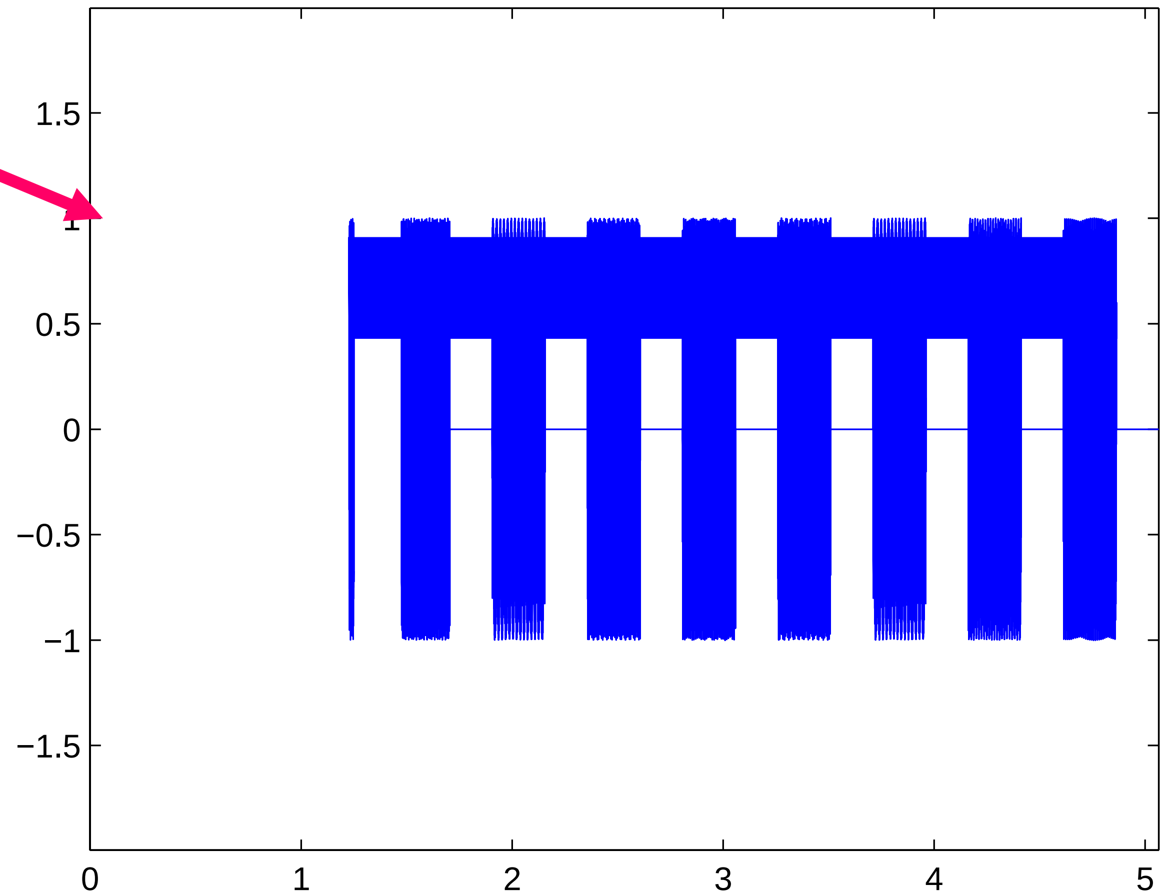
Sending and deciphering noisy signals

- Randomly choose a button
  - Choose random row and column numbers
- Construct the real signal (**`MakeShowPlay`**)
- Add noise to the signal (**`SendNoisy`**)
- Compute cosines to decipher the signals (**`ShowCosines`**)
- See **`Eg13_2`**

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

“Perfect” signal



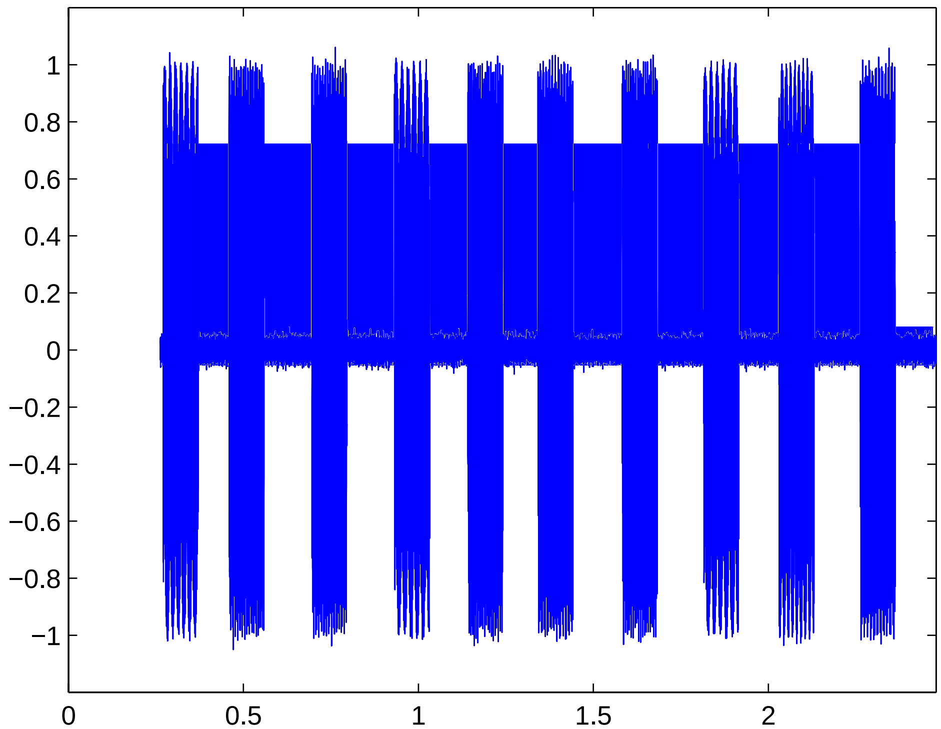


Each band matches one of the twelve “fingerprints”

Buttons pushed at equal time intervals

One of the most difficult problems is how to <u>segment</u> the multi-button signal!

“Noisy” signal



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

Buttons pushed at unequal time intervals