Sampling

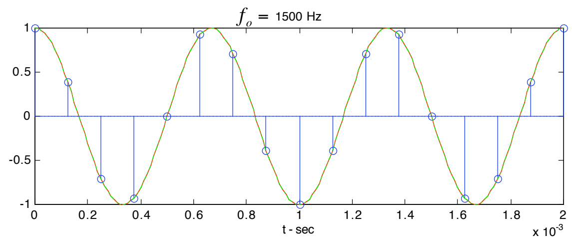
$$x(t) = \cos(2\pi 1500 t)$$

$$t = T_s n$$

$$x[n] = \cos(2\pi \cdot 1500 \cdot T_s n)$$

$$f_s = 8000 \quad Hz \qquad T_s = \tfrac{1}{f_s} = \tfrac{1}{8000} \quad \text{sec}$$

$$x[n] = \cos(2\pi \cdot 1500 \cdot \tfrac{1}{8000} n)$$



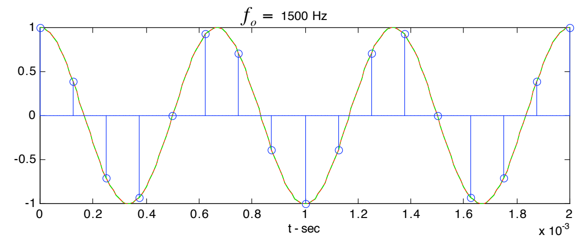
Shannon Sampling Theorem

$$f_s > 2 f_{\max} \longrightarrow f_{\max} < f_s/2$$

$$f_s = 2 f_{\max} \qquad \textit{Nyquist rate}$$

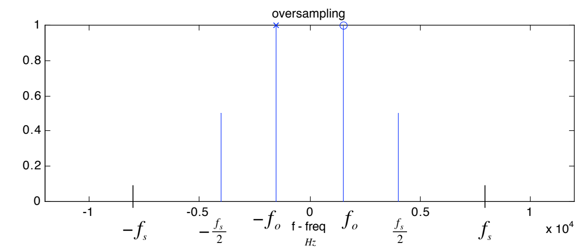
$$t = T_s n$$

$$T_s = \tfrac{1}{f_s}$$

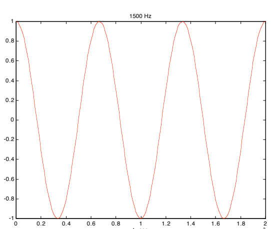


$f_s = 8000 Hz$

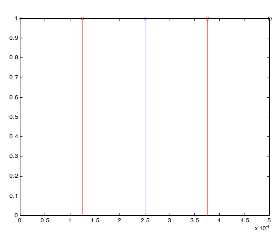
$2A$



Time domain



x

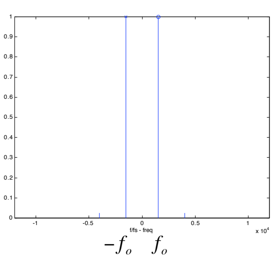


$0 \quad T_s \quad 2T_s \quad 3T_s \quad 4T_s$

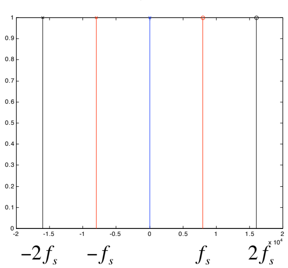
sampling

Frequency domain

$2A$

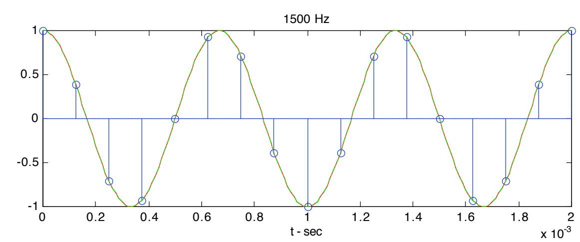


$2A$

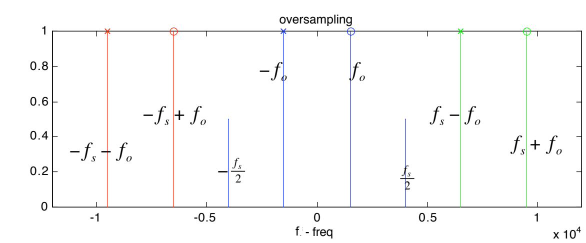


comb

sampled sinewave



$2A$



sinewave spectrum copied around each comb "tooth"

D-to-C only reconstructs frequencies between

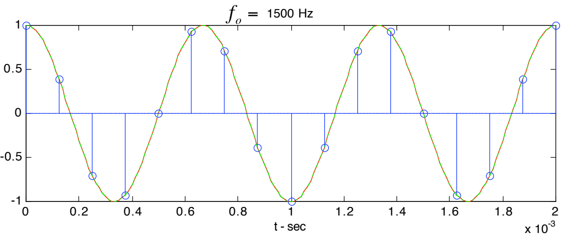
$-\frac{f_s}{2} \le f \le \frac{f_s}{2}$

Normalized frequency

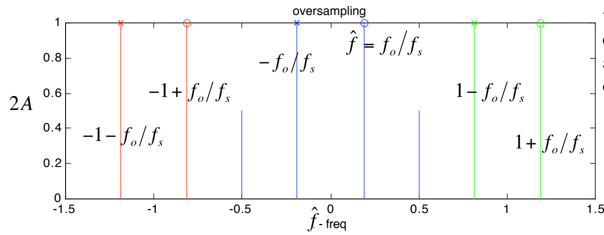
$$x[n] = x(nT_s) = \cos(2\pi f_o nT_s) = \cos(\omega_o nT_s)$$

$$\hat{\omega} = \omega T_s \qquad \hat{f} = \hat{\omega}/(2\pi) = fT_s = f/f_s$$

$$x[n] = \cos(2\pi\hat{f}n) = \cos(n\hat{\omega})$$



frequencies divided by sampling rate



o +freq
x -freq
R -copy
B orig
G +copy

waveform spectrum copies centered at integer values of $\hat{f}$

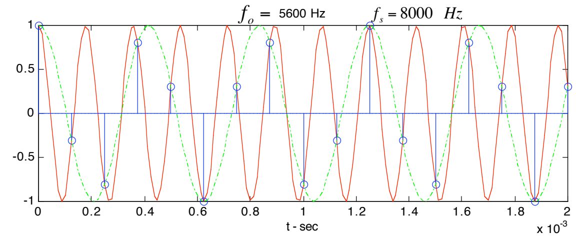
Shannon Sampling Theorem

$\hat{f}_{\max} < \frac{1}{2}$

Sampling: Folding

$\frac{f_s}{2} < f_o < f_s$

$0.5 < \hat{f}_o < 1$



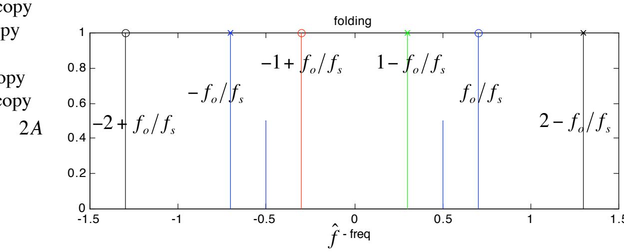
$f_o \uparrow, f_{apparent} \downarrow$

$f_{apparent} = f_s - f_o$

$= 8000 - 5600Hz$

$= 2400Hz$

o +freq
x -freq
K 2nd - copy
R 1st -copy
B orig
G 1st +copy
K 2nd +copy



$\hat{f}_{Bo} > \frac{1}{2}$

$\hat{f}_{Bx} < -\frac{1}{2}$

reconstructed

$0 > \hat{f}_{Gx} > \frac{1}{2}$

$-\frac{1}{2} < \hat{f}_{Ro} < 0$

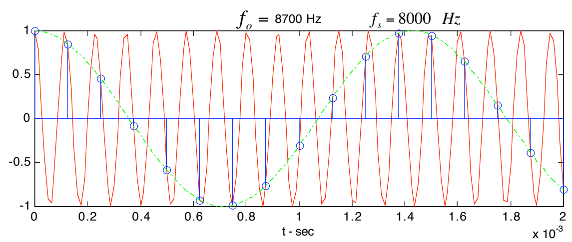
$x > o$

" flipped"

Sampling: Aliasing

$f_s \le f_o < 1.5 f_s$

$1 \le \hat{f}_o < 1.5$



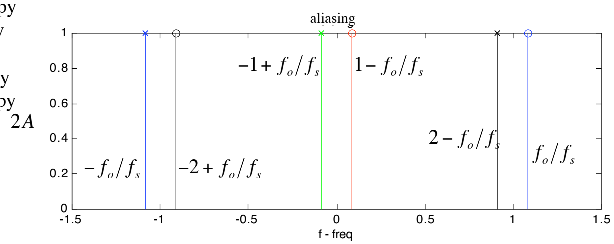
$f_o \uparrow, f_{apparent} \uparrow$

$f_{apparent} = f_o - f_s$

$= 8700 - 8000Hz$

$= 800Hz$

o +freq
x -freq
K 2nd - copy
R 1st -copy
B orig
G 1st +copy
K 2nd +copy



$\hat{f}_{Bo} > 1$

$\hat{f}_{Bx} < -1$

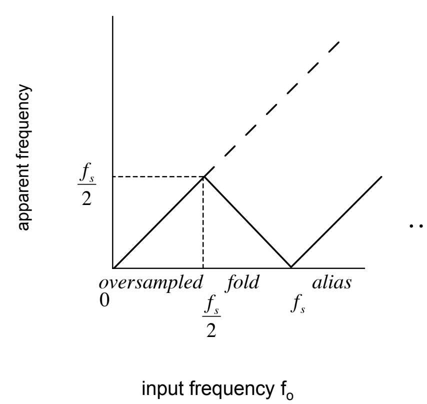
reconstructed

$0 > \hat{f}_{Ro} > \frac{1}{2}$

$-\frac{1}{2} < \hat{f}_{Gx} < 0$

$o > x$

Sampling:



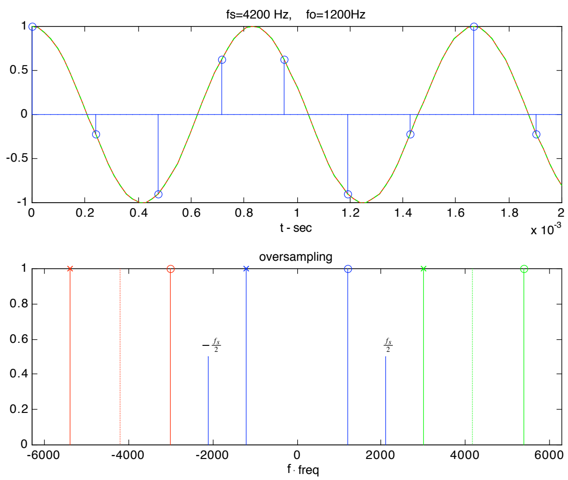
freqramp

Vary Sample rate

$$x(t) = \cos(2\pi 1200 t)$$

$t = T_s n$ $\quad$ vary T_s

$$x[n] = \cos(2\pi \cdot 1200 \cdot T_s n)$$



$2A$

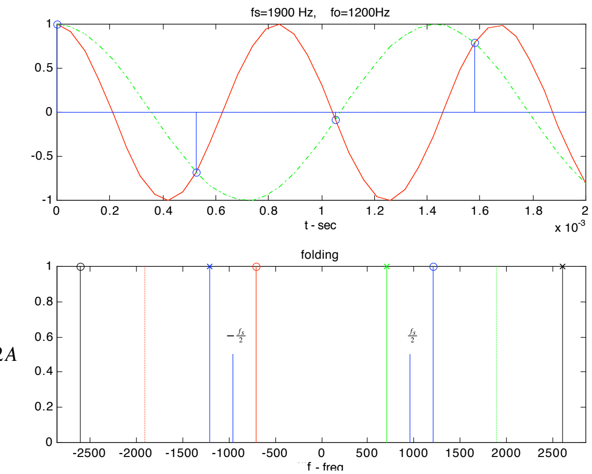
Vary Sample rate

$$x(t) = \cos(2\pi 1200 t)$$

$t = T_s n$ $\quad$ vary T_s

$$x[n] = \cos(2\pi \cdot 1200 \cdot T_s n)$$

folding



$2A$

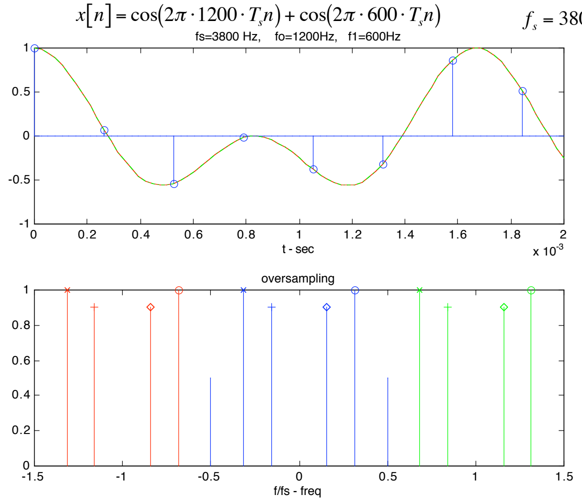
changerate

Sampling: Composite Signal

$$x(t) = \cos(2\pi 1200 t) + \cos(2\pi 600 t)$$

$$x[n] = \cos(2\pi \cdot 1200 \cdot T_s n) + \cos(2\pi \cdot 600 \cdot T_s n)$$

$f_s = 3800Hz$



o +freq1
x -freq1
d +freq2
+ -freq2

R -copy
B orig
G +copy

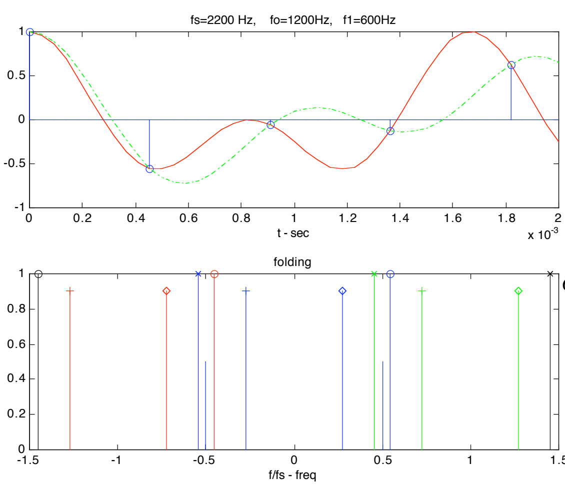
$2A$

Sampling: Composite Signal

$$x(t) = \cos(2\pi 1200 t) + \cos(2\pi 600 t)$$

$$x[n] = \cos(2\pi \cdot 1200 \cdot T_s n) + \cos(2\pi \cdot 600 \cdot T_s n)$$

$f_s = 2200Hz$



o +freq1
x -freq1
d +freq2
+ -freq2
K 2nd - copy
R 1st - copy
B orig
G 1st +copy
K 2nd +copy

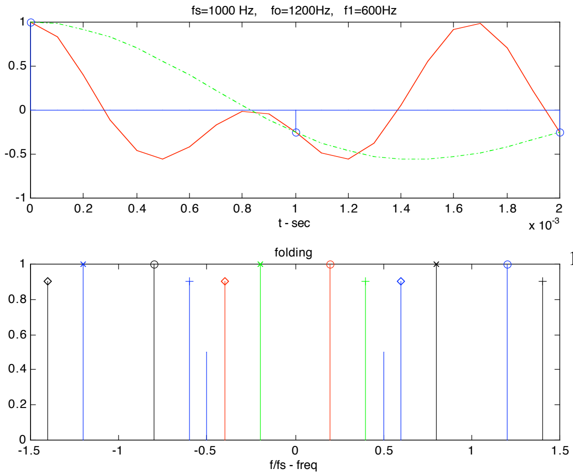
$1200Hz$ *folded*
$600Hz$ *oversample*

Sampling: Composite Signal

$$x(t) = \cos(2\pi 1200t) + \cos(2\pi 600t)$$

$$x[n] = \cos(2\pi \cdot 1200 \cdot T_s n) + \cos(2\pi \cdot 600 \cdot T_s n) \qquad f_s = 1000\,Hz$$

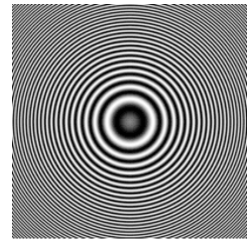
o +freq1
x -freq1
d +freq2
+ -freq2
K 2nd - copy
R 1st - copy
B orig
G 1st +copy
K 2nd +copy

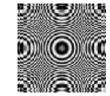


$1200Hz$ *folded*
$600Hz$ *fold*

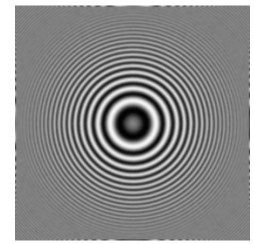
Aliased Voice Expt.

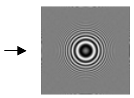
Resampling





Resized (nearest-
Neighbor)
no pre-blur





Resized (nearest-
Neighbor)
with pre-blur

Psychophysics

the relationship between physical stimuli and what you perceive

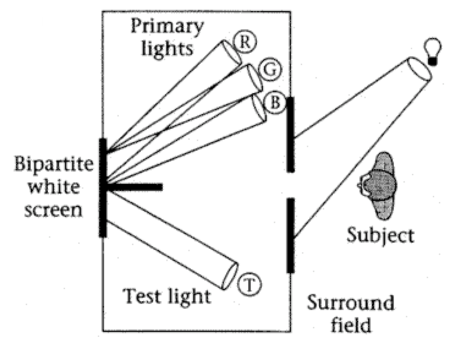
absolute thresholds, discrimination thresholds, and scaling.

Threshold: the point of intensity that you can just detect the presence of, or difference in, a stimulus.
absolute threshold -- level at which the subject is able to detect the presence of the stimulus (50%)
difference threshold -- the difference between two stimuli of differing intensities you can detect (50%)
adjust one stimulus until it is perceived as the same as the other,
describe the magnitude of the difference between two stimuli
detect a stimulus against a background.
discrimination experiments --what point the difference between two stimuli is detectable.

http://en.wikipedia.org/wiki/Psychophysics

Psychophysics:Vision

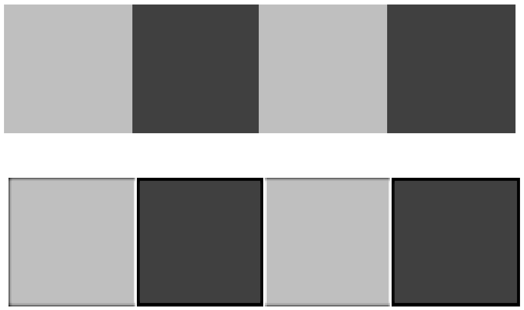
Color Matching

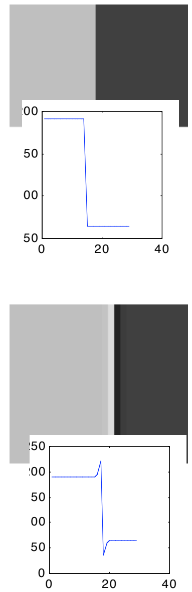


Turn knobs for R,G, &B until combined light matches color of test light.

http://www.ling.upenn.edu/courses/ling525/color_vision.html

Psychophysics: Vision





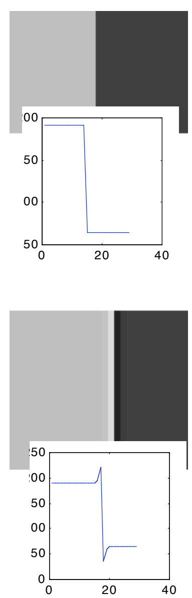
Psychophysics: Vision
Unsharp Mask

By exaggerating contrast along edges in the image, the edges stand out more, making them appear sharper.”

Psychophysics: Vision
Unsharp Mask

before

after unsharp mask



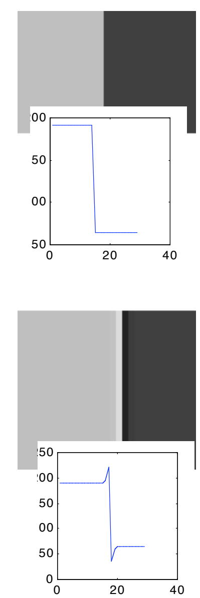
Psychophysics: Vision
Unsharp Mask

original

+

invert
+
blur

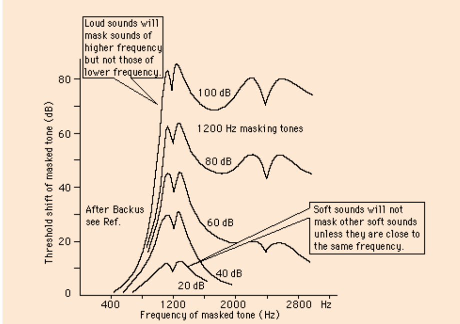
“unsharp mask”



Psychoacoustics: Sound Masking

You know I can't hear you when the water is running!
This statement carries the essentials of the conventional wisdom about sound masking. Low-frequency, broad banded sounds (like water running) will mask higher frequency sounds which are softer at the listener's ear (a conversational tone from across the room)

Shown are the masking effects of 1200 Hz tones of various intensities. Note that it is effective in masking sounds above it in frequency, but not below. The dips at 1200 and 2400 come from the effects of beats.



http://hyperphysics.phy-astr.gsu.edu/hbase/sound/mask.html

Broadband white noise tends to mask all frequencies, and is approximately linear in that masking. By linear you mean that if you raise the white noise by 10 dB, you have to raise everything else 10 dB to hear it. -- http://hyperphysics.phy-astr.gsu.edu/hbase/sound/mask.html

Chirp
+1200Hz

Psychoacoustics

The following MATLAB function performs a simple psychoacoustic test. It creates bandlimited noise, centered at 1000 Hz and also creates a sinusoid. It then plays the noise alone and then the noise plus the sinusoid. Try different values of f and A to see whether you can detect the sinusoid. For a particular value of f we'll call A_{min}(f) the minimum amplitude at which the frequency f sinusoid could still be heard. Plot several values on the graph of f vs. A_{min} to determine a simple masking curve.

```
A typical masking experiment might proceed as follows. A
short, about 400 msec, pulse of a 1,000 Hz sine wave
acts as the target, or the sound the listener is trying
to hear. Another sound, the masker, is a band of noise
centered on the frequency of the target (the masker
could also be another pure tone). The intensity of the
masker is increased until the target cannot be heard
```

Psychoacoustics

mask.m plays noise, then noise plus a sinewave of amplitude A and frequency f. You are supposed to determine the smallest amplitude that you can hear the sinewave over the noise. Repeat this for several values of f, and plot f vs. A_{min}.

mask.m is linked to the course webpage.
http://ssi.www.media.mit.edu/courses/ssi/y05/ps4/mask.m

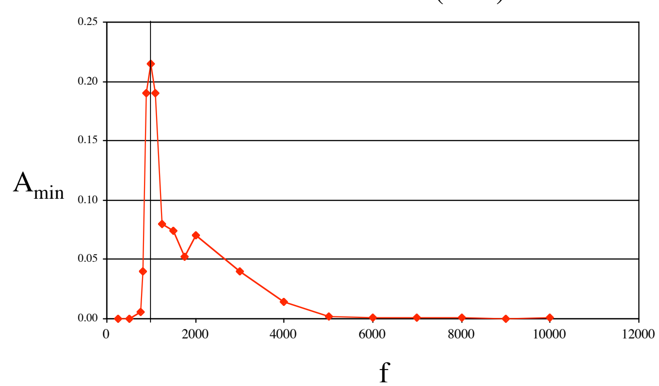
Tip:
In mask.m change

```
sound(wf,22050)
A                    %add so you get feedback of A
%pause               %comment out, so you don't wait
sound(wf+s,22050)
```

>> f=1000; for A=0.01:.01:.1; mask(f,A); end

Press cmd+. to stop when you detect sinewave.

Minimum audible sinusoid amplitude with noise centered at 1000Hz (A=1)



f	A_{min}
250	0.0003
500	0.00003
750	0.006
825	0.03
900	0.19
1000	0.215
1100	0.19
1250	0.08
1500	0.074
1750	0.052
2000	0.07
3000	0.04
4000	0.014
5000	0.0023
6000	0.001
7000	0.0012
8000	0.0007
9000	0.0004
10000	0.0007