Introduction to Music Synthesis

Dr. John Fattaruso
http://www.physics.smu.edu/fattarus/

Dr. John Fattaruso

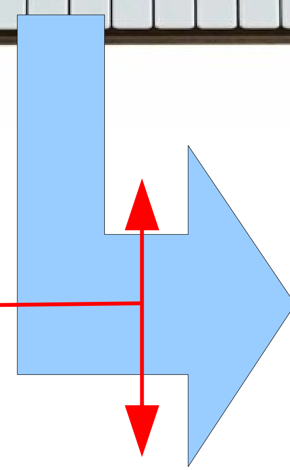
Background

- Ph.D. Electrical Engineering, U. C. Berkeley; minors Electromagnetic theory, Statistics
- ~22 years at Texas Instruments; Analog circuit and solid state device design; Distinguished Member of the Technical Staff
- ~40 years of numerical programming
- Adjunct faculty at SMU in Physics and EE departments; currently teaching Phys3340 Computational Physics and KNW2300 Introduction to Engineering Design
- 30 years member of Dallas Symphony Chorus

Music Synthesis

What's inside the box?

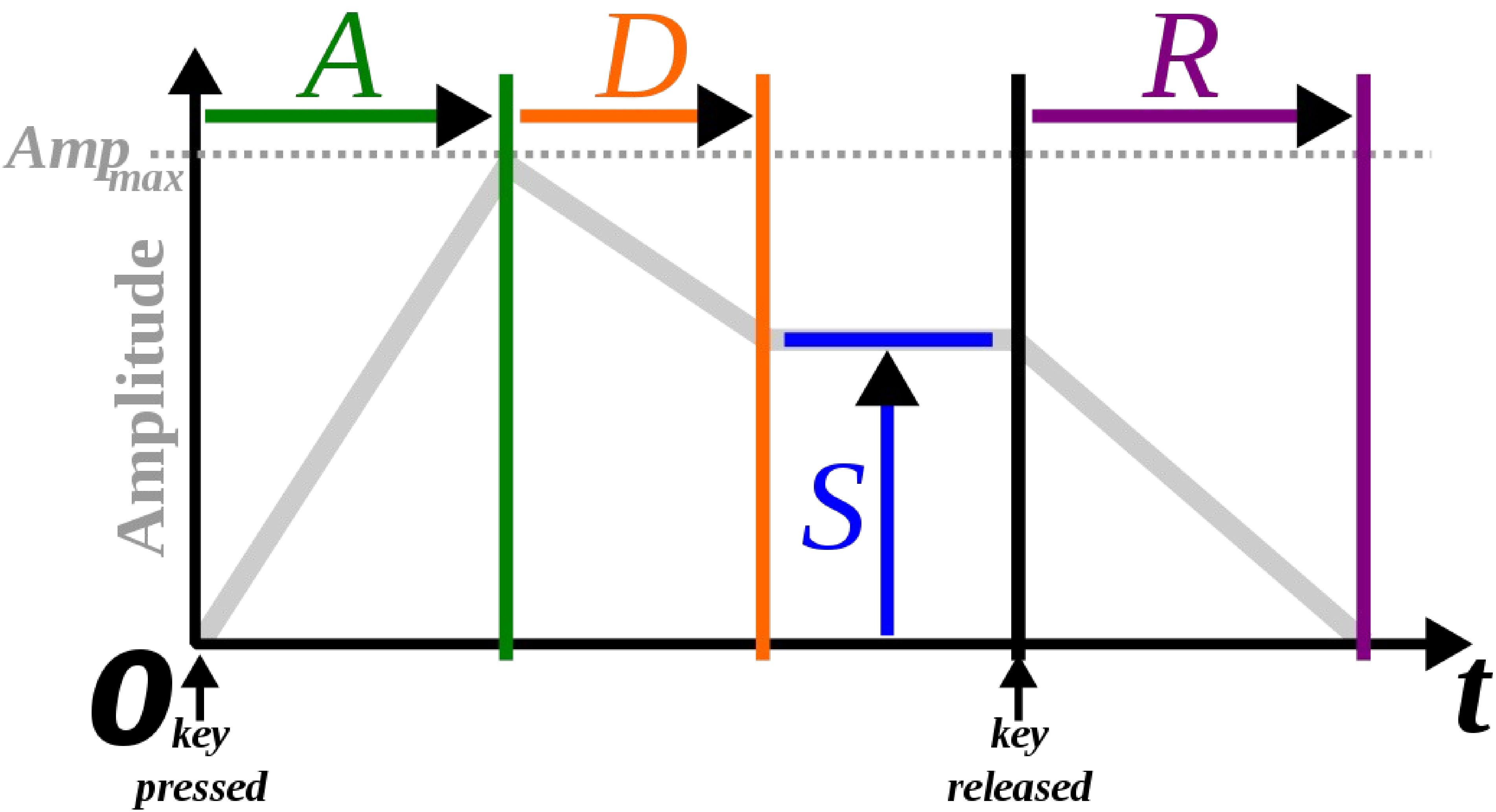
Pitch bend wheel



Associate a keyboard key and pitch bend wheel position to a given electronic frequency

NOTE	Frequency in Hz				
	3rd Octave	4th Octave	5th Octave	6th Octave	7th Octave
C	130.81	261.63	523.25	1046.5	2093.0
Db	138.59	277.18	554.37	1108.7	2217.5
D	146.83	293.66	587.33	1174.7	2349.3
Eb	155.56	311.13	622.25	1244.5	2489.0
E	164.81	329.63	659.26	1318.5	2637.0
F	174.61	349.23	698.46	1396.9	2793.8
F#	185.00	369.99	739.99	1480.0	2960.0
G	196.00	392.00	783.99	1568.0	3136.0
Ab	207.65	415.30	830.61	1661.2	3322.4
A	220.00	440.00	880.00	1760.0	3520.0
Bb	233.08	466.16	932.33	1864.7	3729.3
B	246.94	493.88	987.77	1975.5	3951.1

"ADSR" Envelopes



"Attack" "Decay" "Sustain" "Release"

All musical notes synthesized with various timbres are played within an amplitude envelope designed to mimic the starting transient and sustained sound generation of physical instruments

Example Audio Samples

Example with attack, decay, and release times slowed way down for recognition:
http://www.physics.smu.edu/fattarus/audio_ADSR.wav

Synthesis Methods

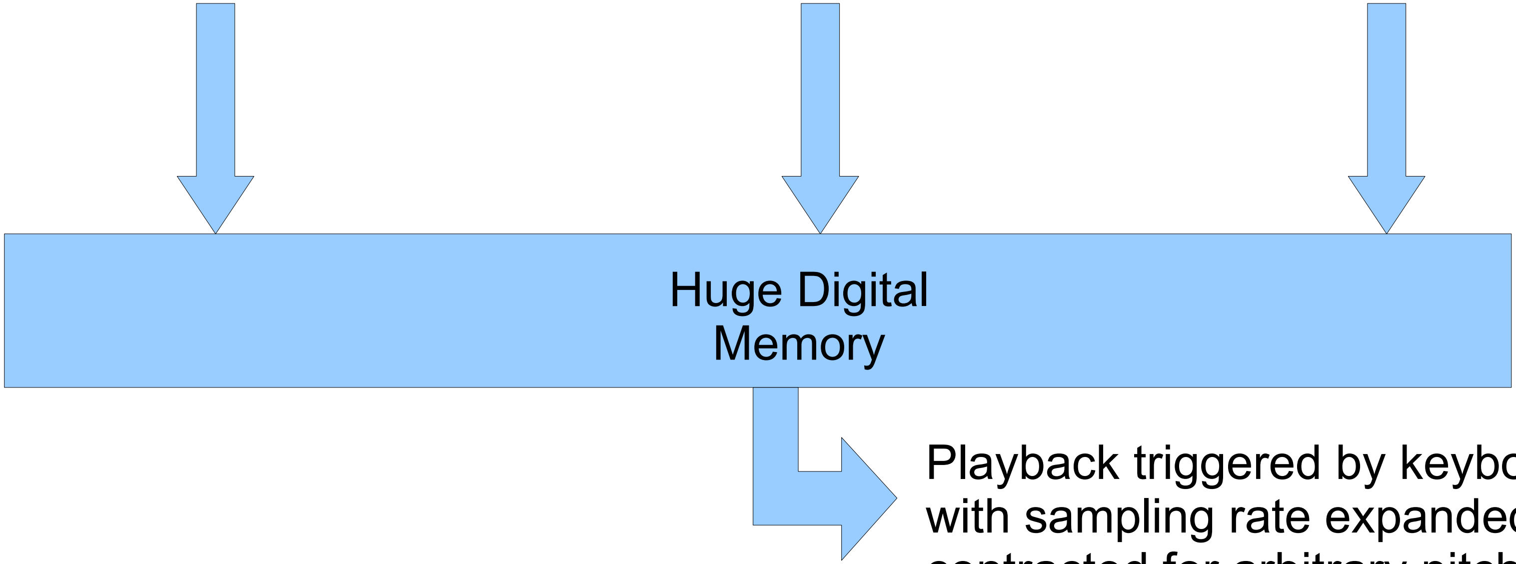
•Physical instrument sampling

•Additive (build up synthetic waveform from wanted harmonic content)

•Subtractive (filter out unwanted harmonics from a harmonically rich source)

•Frequency modulation

Record Samples of Each Intrument



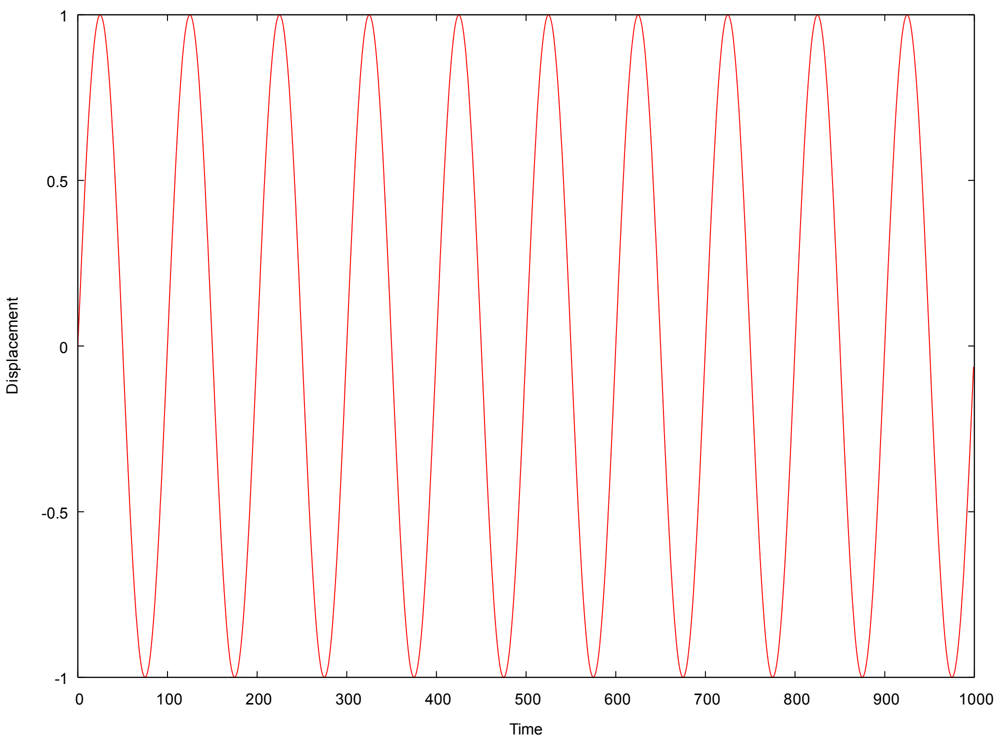
Playback triggered by keyboard with sampling rate expanded or contracted for arbitrary pitch

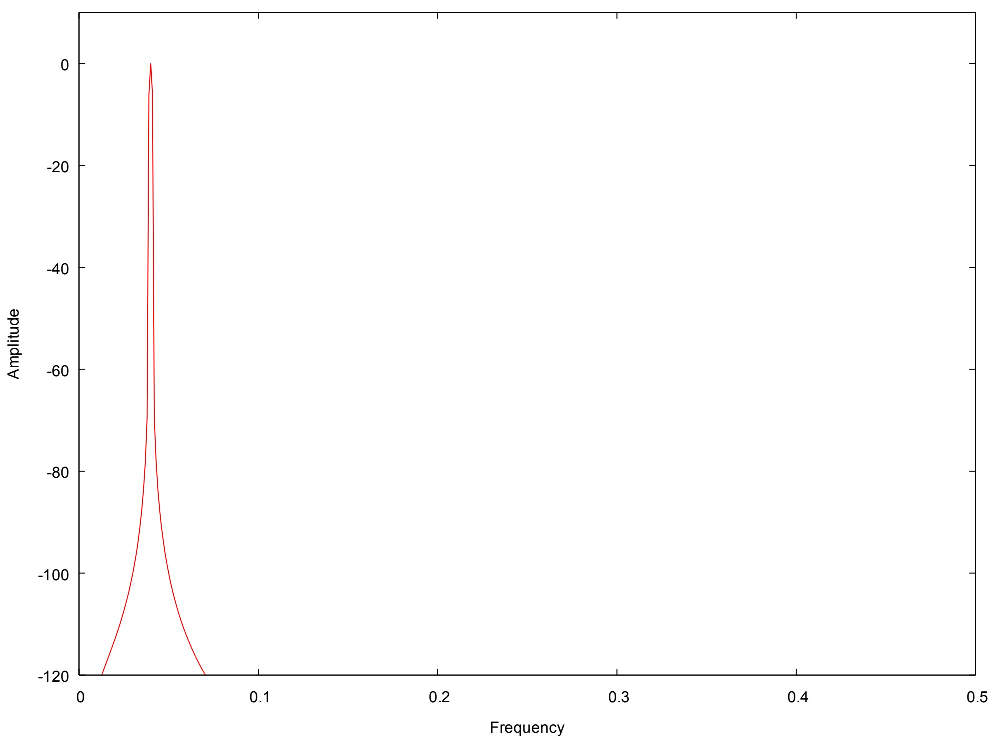
Synthesis Methods

- Physical instrument sampling
- Additive (build up synthetic waveform from wanted harmonic content)
- Subtractive (filter out unwanted harmonics from a harmonically rich source)
- Frequency modulation

Sinusoidal Source

Fundamental frequency only



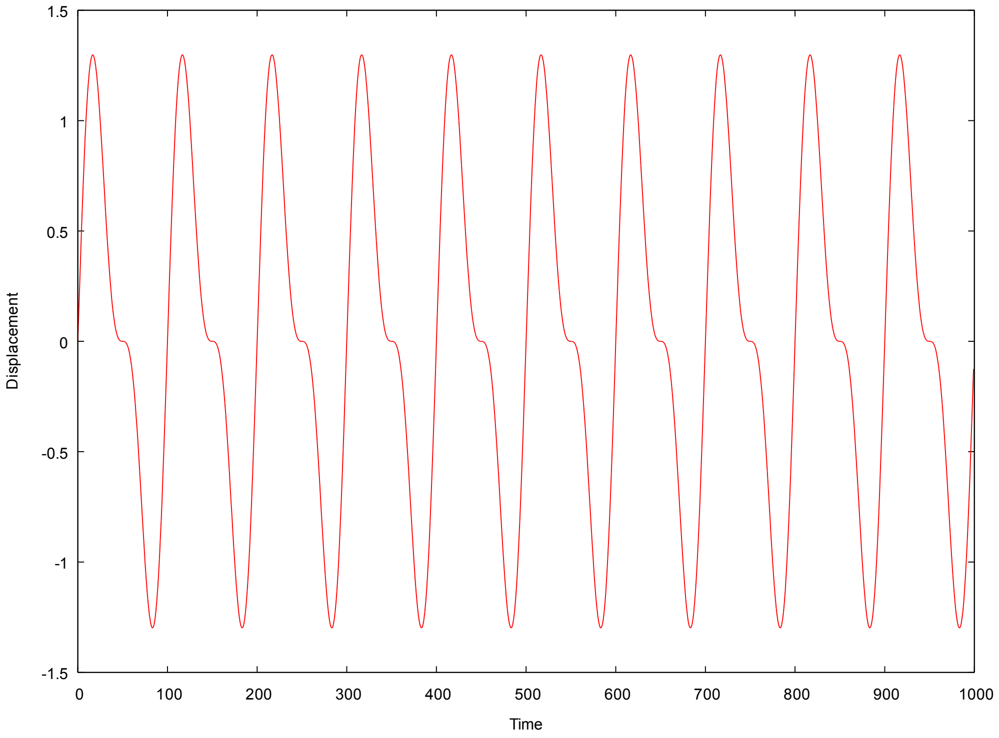


Waveform

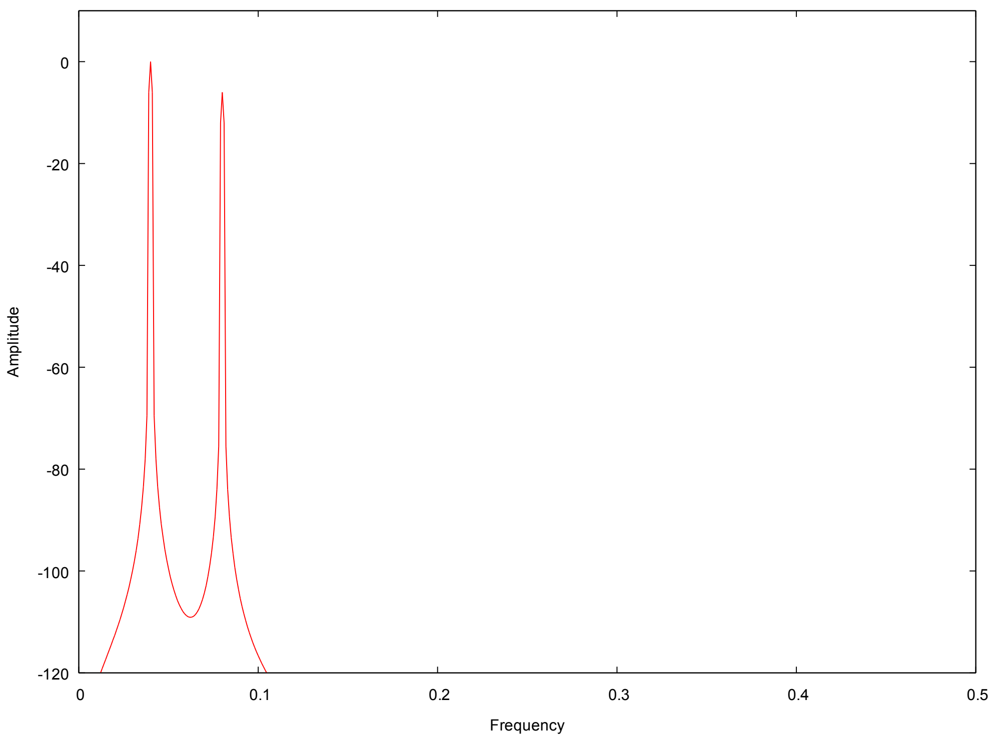
Spectrum

Sinusoidal Source

Fundamental plus second harmonic at zero phase shift



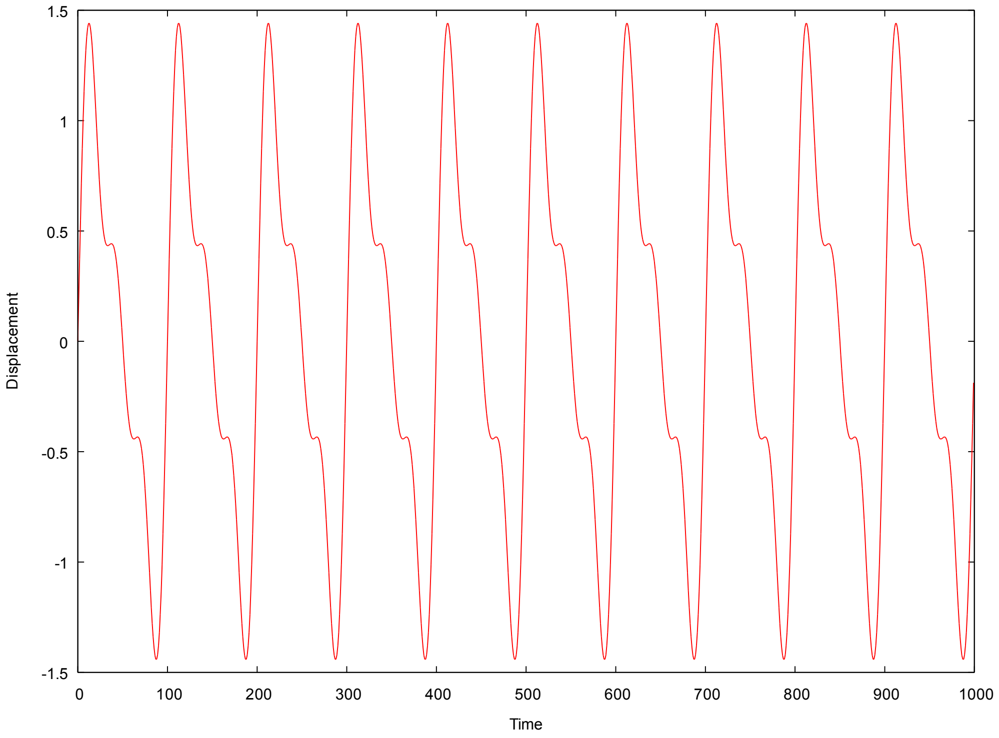
Waveform



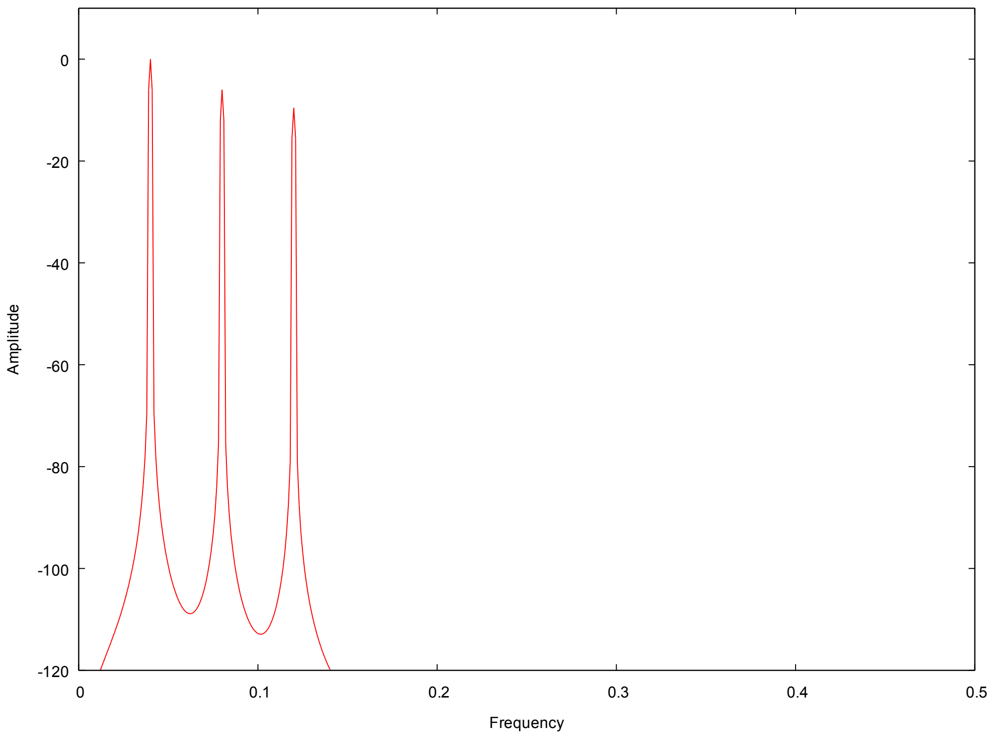
Spectrum

Sinusoidal Source

Fundamental plus second and third harmonics at zero phase shift



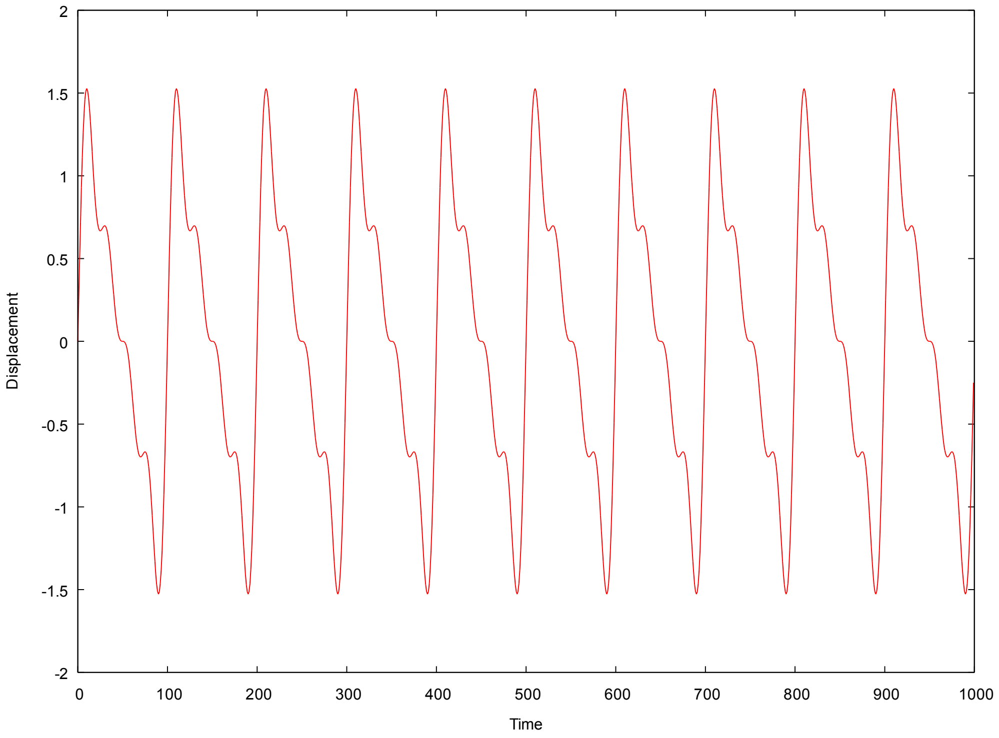
Waveform



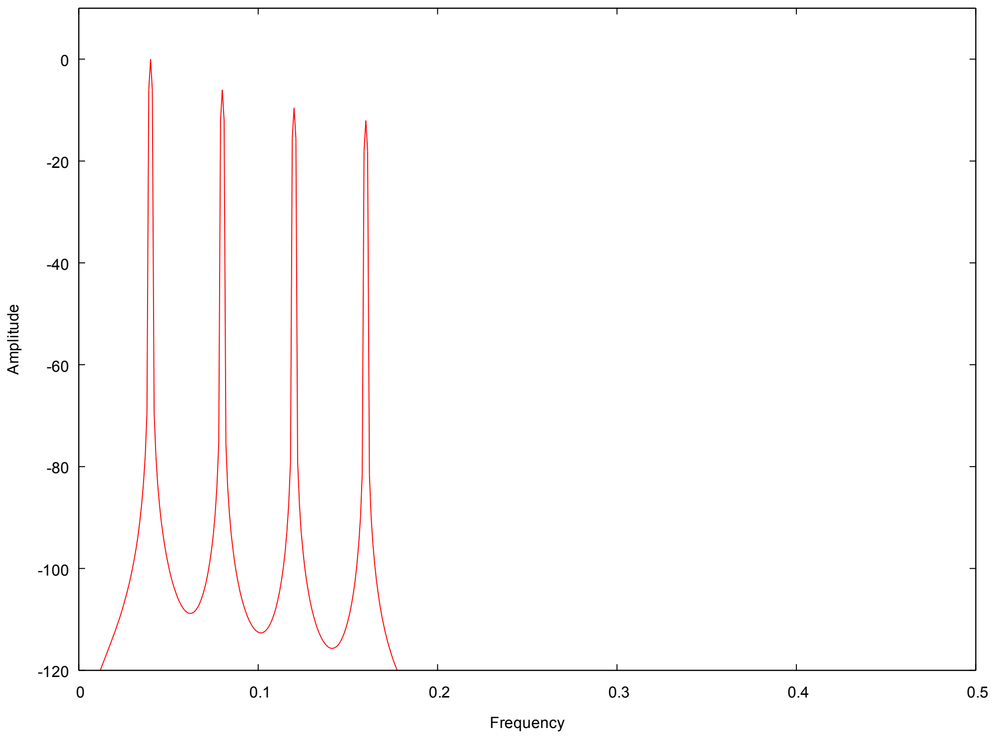
Spectrum

Sinusoidal Source

Fundamental plus second, third, and fourth harmonics at zero phase shift



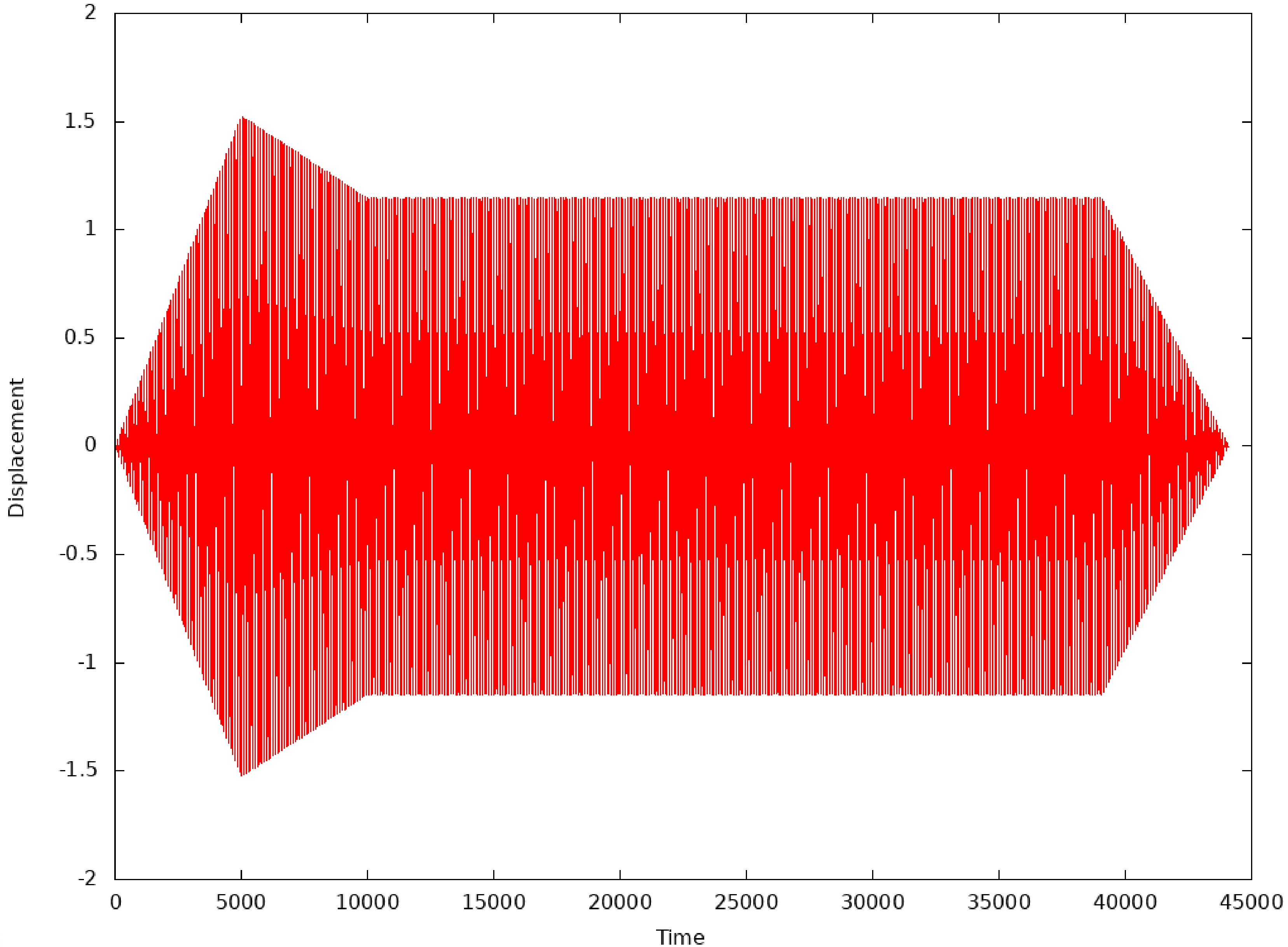
Waveform



Spectrum

Full Synthesized Harmonic Waveform

Sampling rate is 44100 samples/second, so entire synthesized note in its ADSR envelope is one second in duration:



Example Audio Samples

Fundamental only, 500 Hz:
http://www.physics.smu.edu/fattarus/audio_harm_1.wav

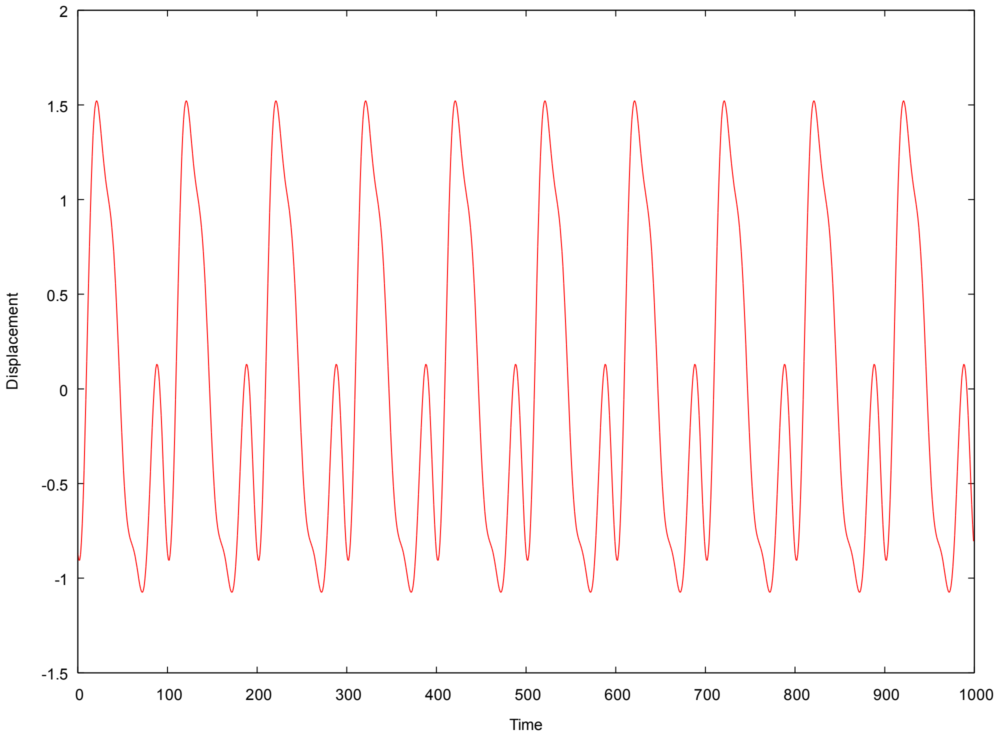
Fundamental through 2nd harmonic:
http://www.physics.smu.edu/fattarus/audio_harm_2.wav

Fundamental through 3rd harmonic:
http://www.physics.smu.edu/fattarus/audio_harm_3.wav

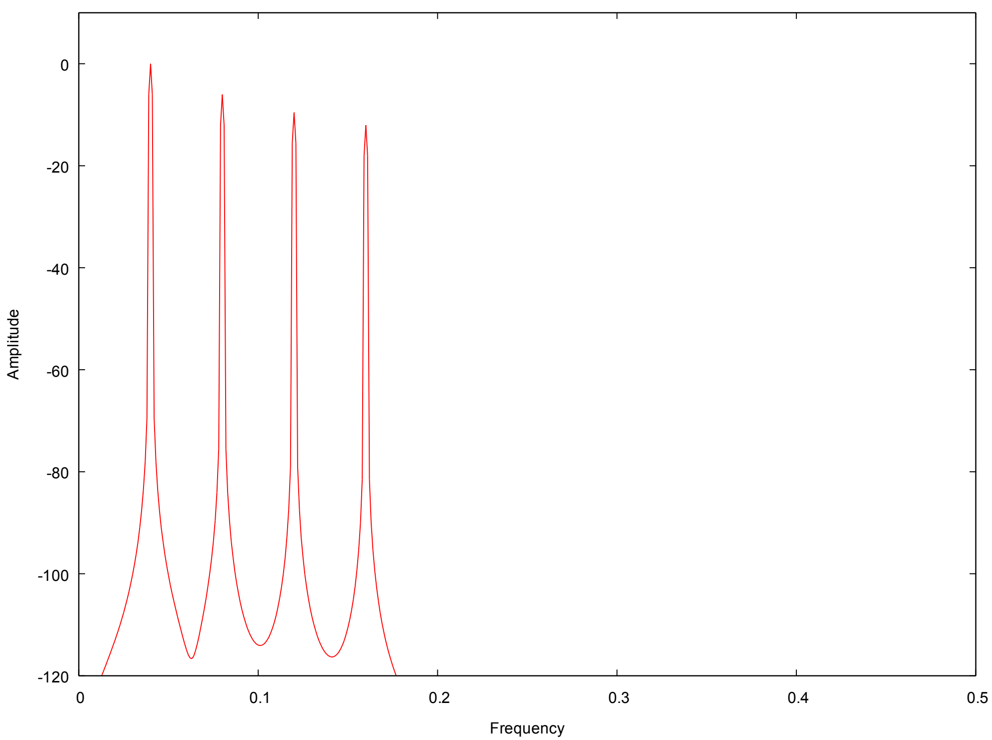
Fundamental through 4th harmonic:
http://www.physics.smu.edu/fattarus/audio_harm_4.wav

Sinusoidal Source

Fundamental plus second, third, and fourth harmonics
at 180 degrees phase shift relative to fundamental



Waveform



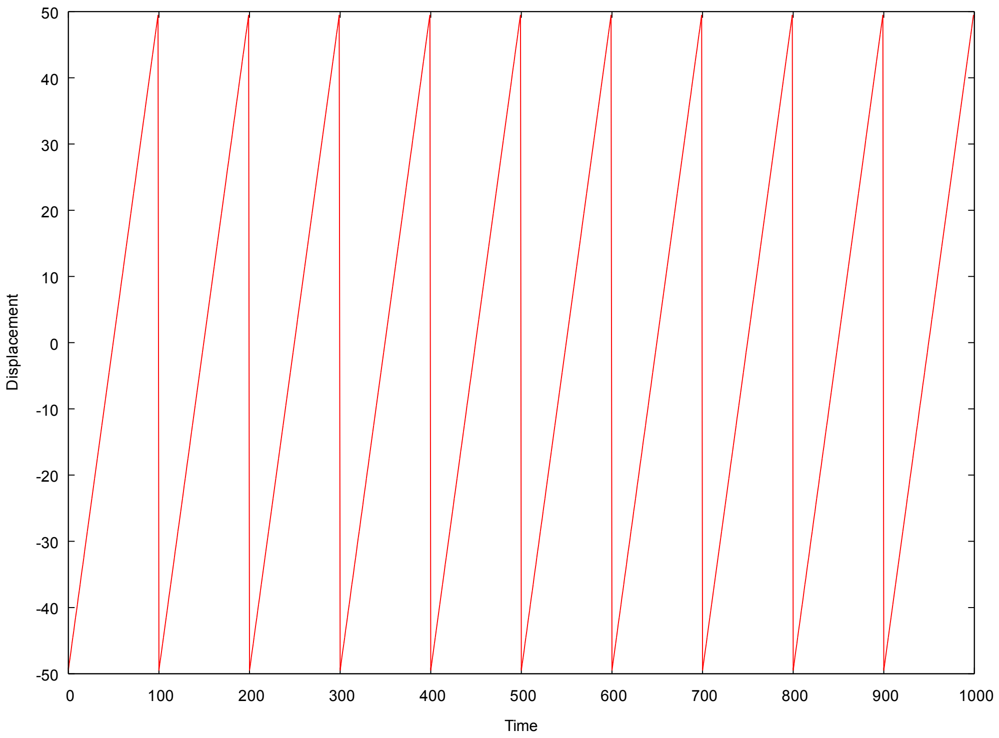
Spectrum

Fundamental through 4th harmonic at 180 degrees phase shift relative to fundamental:
http://www.physics.smu.edu/fattarus/audio_harm_4_p180.wav

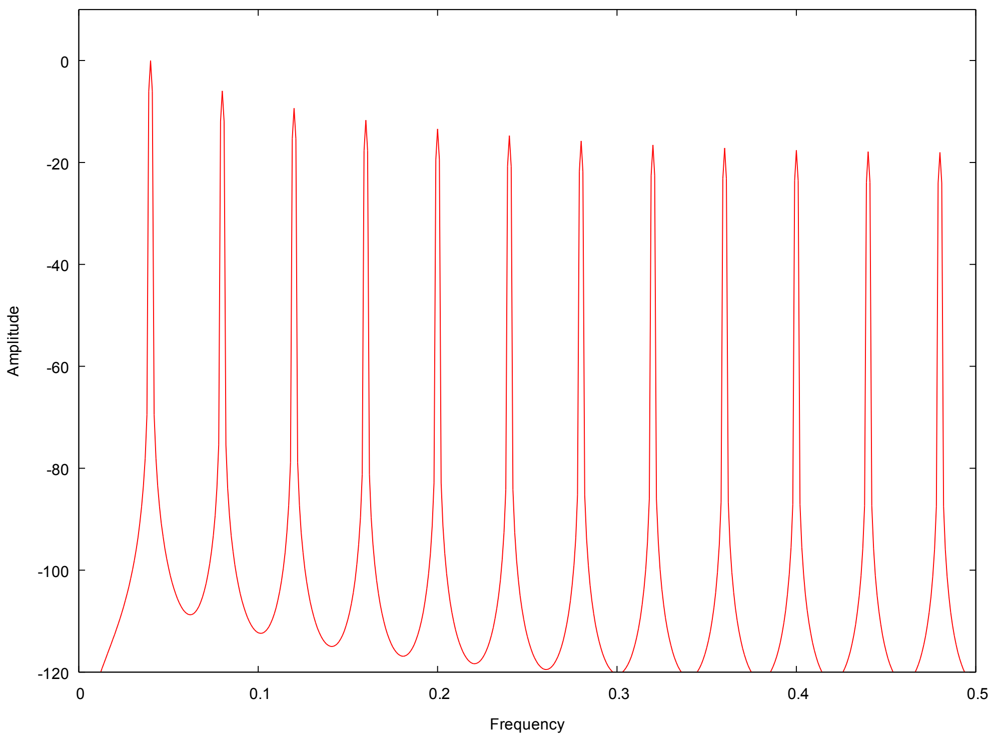
Synthesis Methods

- Physical instrument sampling
- Additive (build up synthetic waveform from wanted harmonic content)
- Subtractive (filter out unwanted harmonics from a harmonically rich source)
- Frequency modulation

Sawtooth Source



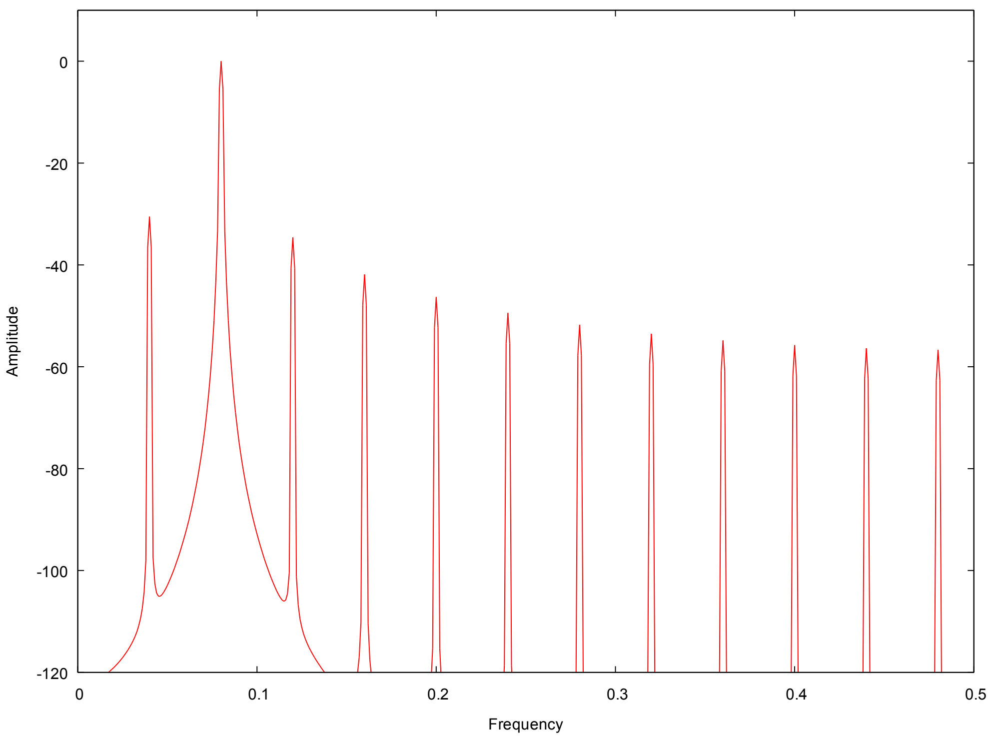
Waveform



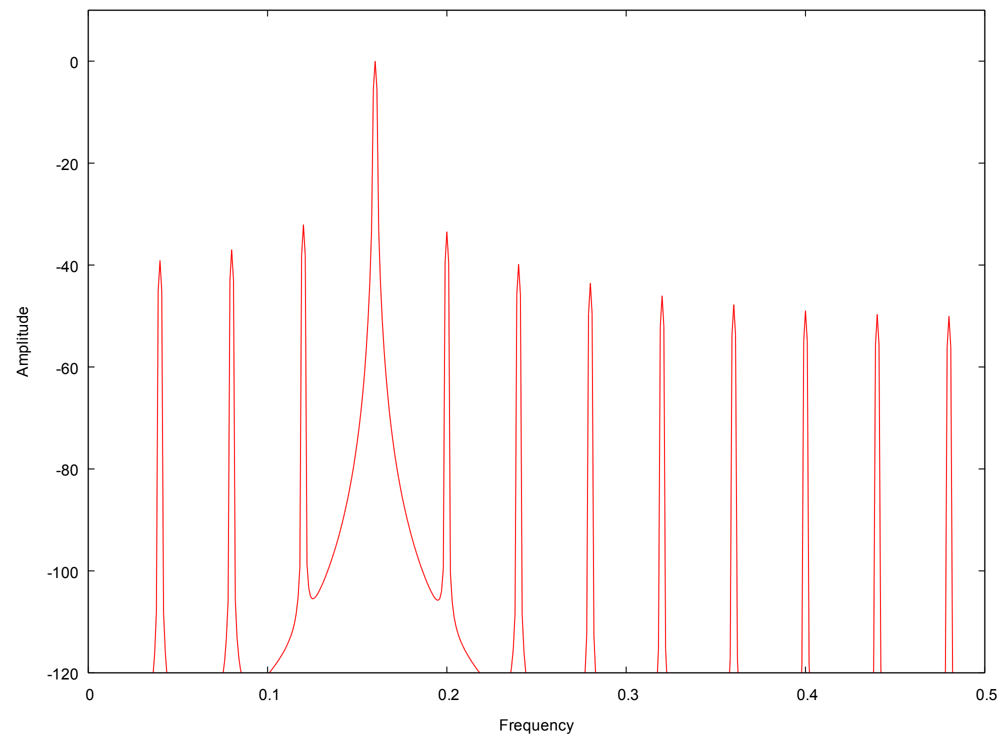
Spectrum

Filtering this harmonically rich source with an electronic resonant circuit is akin to how a physical instrument produces its sound, with a mechanical pulsating excitation and an acoustically resonant structure

Filtered Sawtooth Spectra



Spectrum for filter tuned to second harmonic of excitation



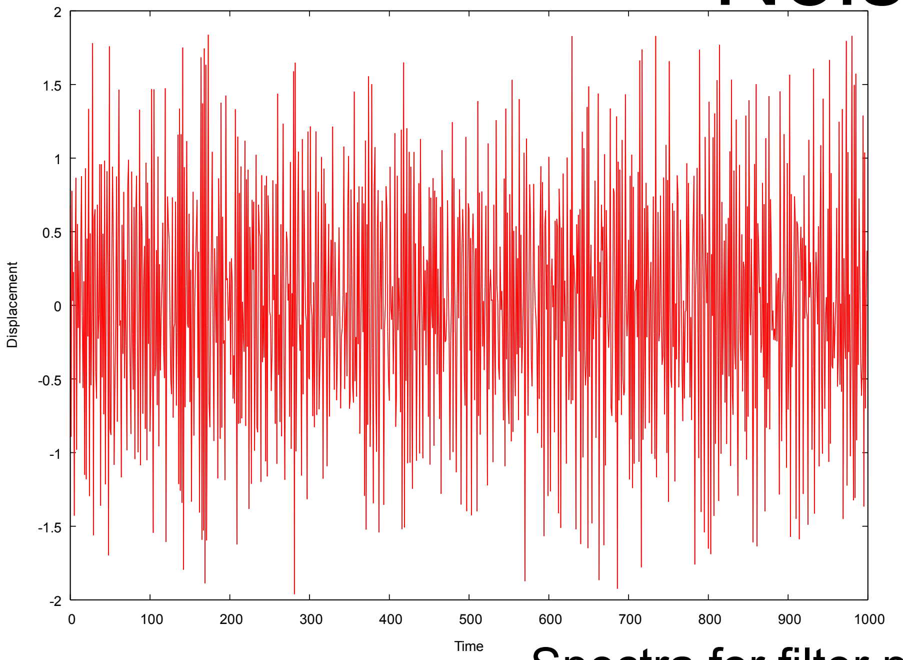
Spectrum for filter tuned to fourth harmonic of excitation

Example Audio Samples

Sawtooth excitation at 250 Hz, filter resonance at 500 Hz:
http://www.physics.smu.edu/fattarus/audio_saw_p88p2.wav

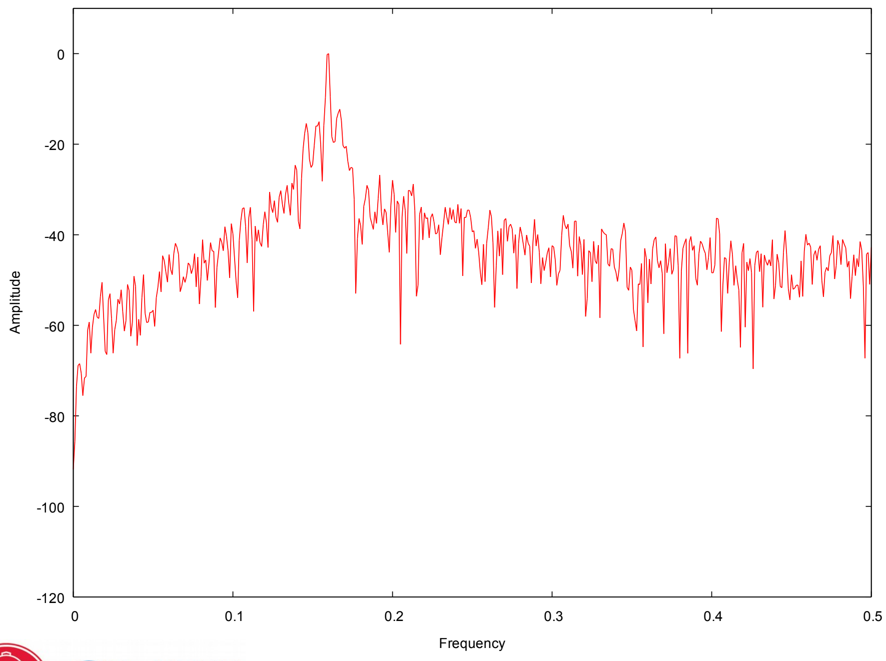
Sawtooth excitation at 250 Hz, filter resonance at 1000 Hz:
http://www.physics.smu.edu/fattarus/audio_saw_p44p1.wav

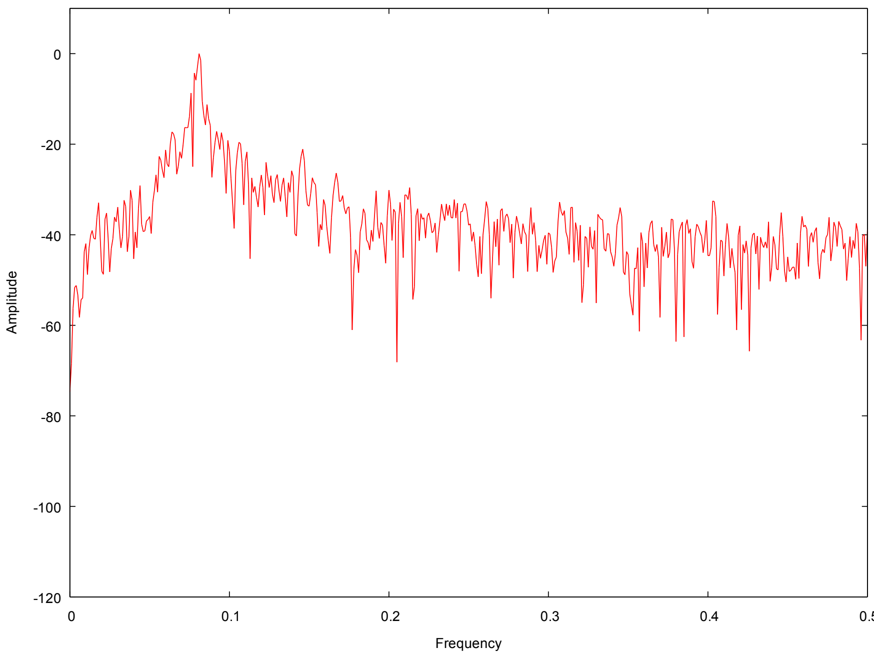
Noise Source



Waveform from a random number generator

Spectra for filter periods= 6.25 and 12.5





Example Audio Samples

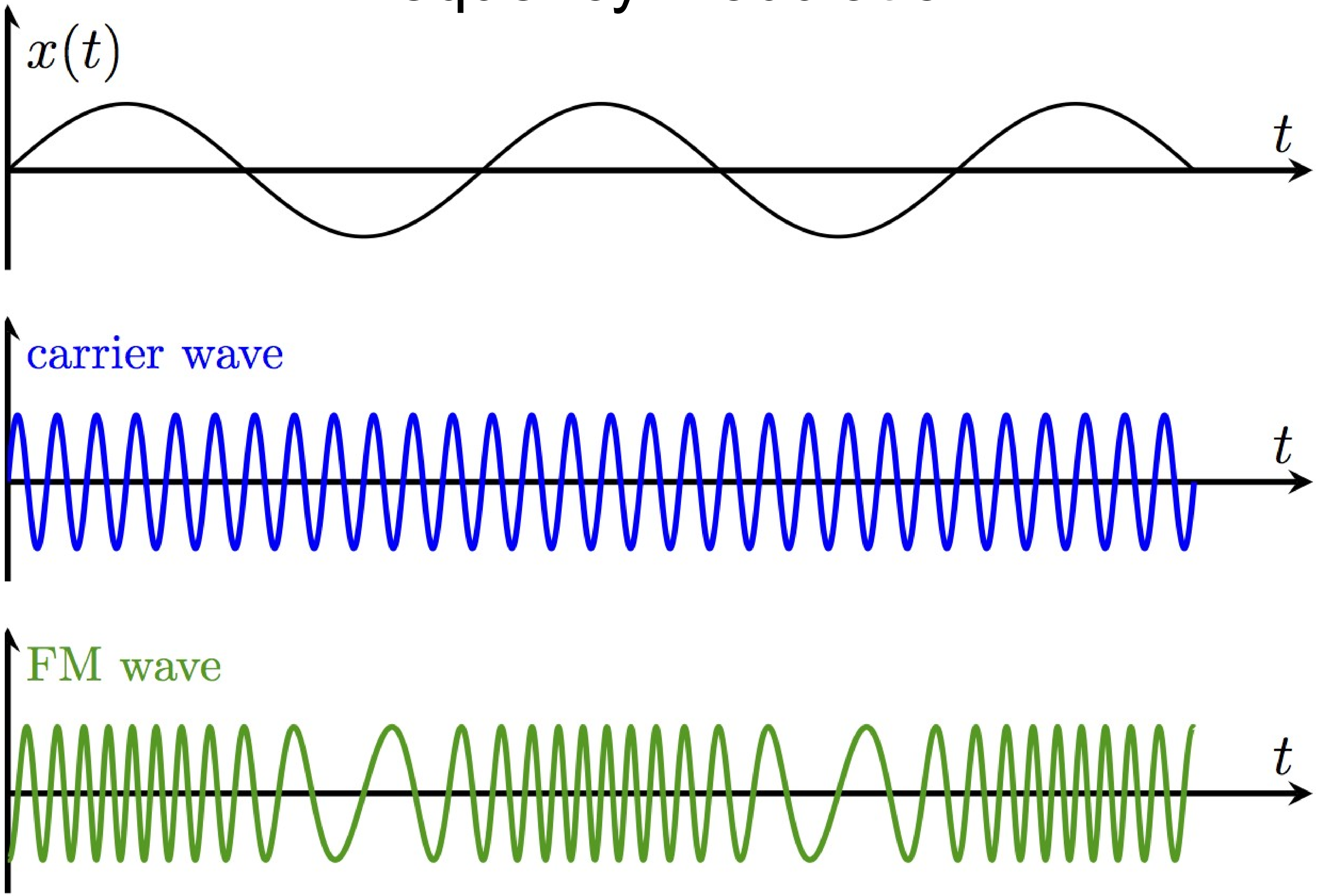
Filter resonance at 500 Hz:
http://www.physics.smu.edu/fattarus/audio_noise_p88p2.wav

Filter resonance at 1000 Hz:
http://www.physics.smu.edu/fattarus/audio_noise_p44p1.wav

Synthesis Methods

- Physical instrument sampling
- Additive (build up synthetic waveform from wanted harmonic content)
- Subtractive (filter out unwanted harmonics from a harmonically rich source)
- Frequency modulation

Frequency Modulation



Amplitude and Frequency Modulation

$$\text{Unmodulated Wave} = A\sin\left(2\pi f_c \cdot t\right)$$

f_c = constant carrier frequency A = constant carrier amplitude

$$\text{AM Wave} = A\left(t\right)\sin\left(2\pi f_c \cdot t\right)$$

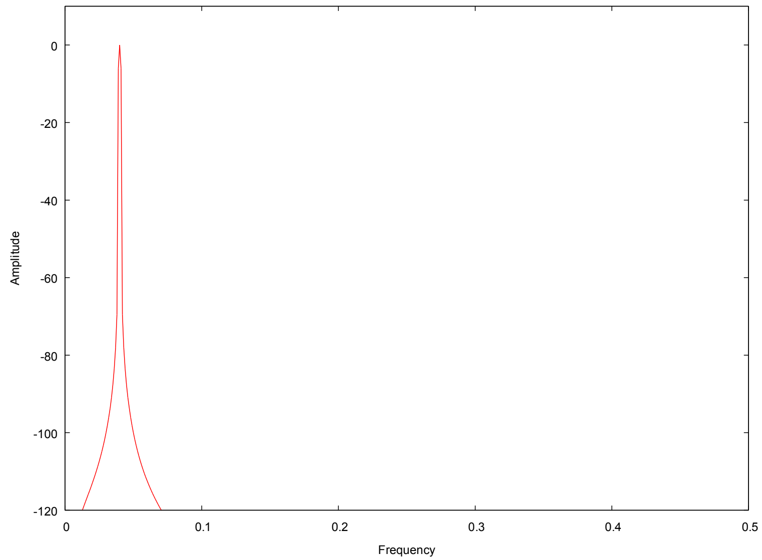
$f_c(t)$ = carrier frequency, a function of the modulation wave and varying with time

$$\text{FM Wave} = A\sin\left(2\pi f_c\left(t\right) \cdot t\right)$$

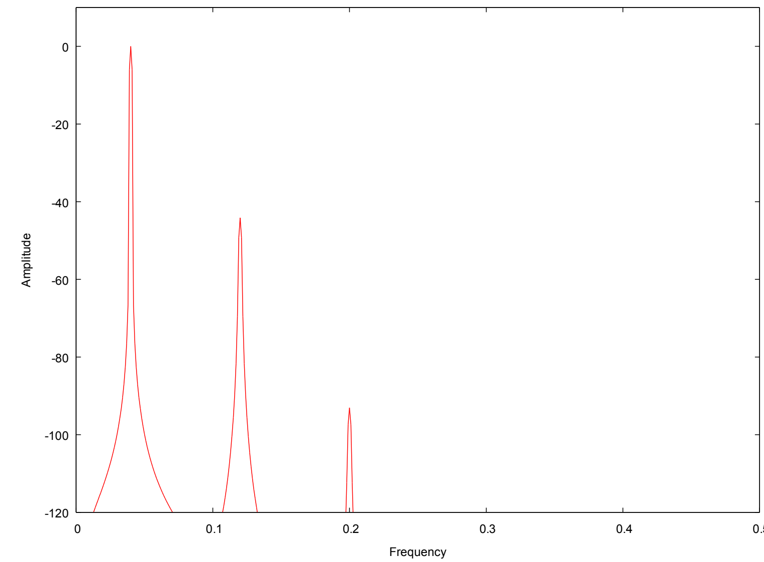
$f_c(t)$ = carrier frequency, a function of the modulation wave and varying with time

Example: $f_c = f_{c0}\left(1+\beta\sin\left(2\pi f_{mod} t\right)\right)$

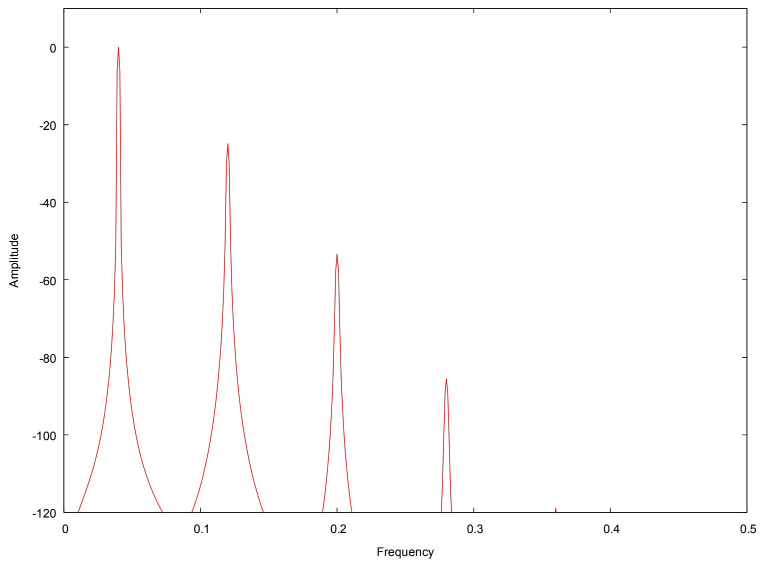
FM Spectra



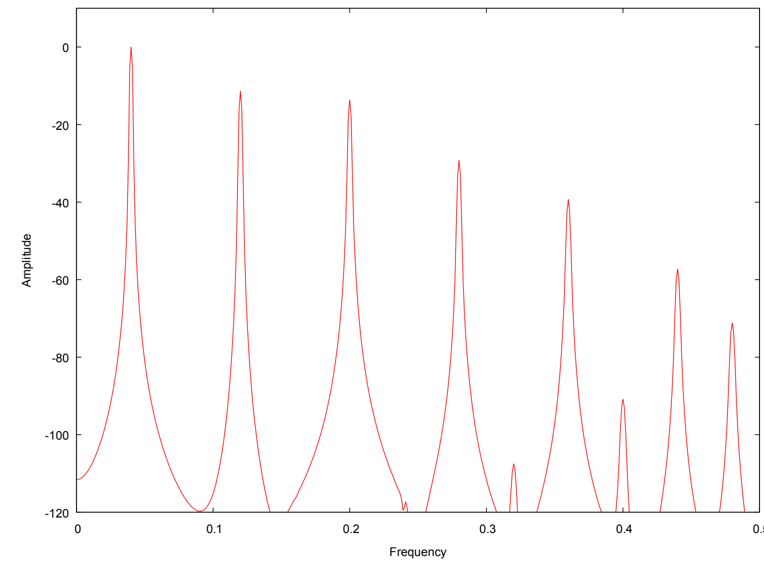
β=0



β=0.0001



β=0.001



β=0.01

Example Audio Samples

Carrier at 250 Hz, FM modulation at 500 Hz with β=0:
http://www.physics.smu.edu/fattarus/audio_fm_b0.wav

Carrier at 250 Hz, FM modulation at 500 Hz with β=0.0001:
http://www.physics.smu.edu/fattarus/audio_fm_b0p0001.wav

Carrier at 250 Hz, FM modulation at 500 Hz with β=0.001:
http://www.physics.smu.edu/fattarus/audio_fm_b0p001.wav

Carrier at 250 Hz, FM modulation at 500 Hz with β=0.01:
http://www.physics.smu.edu/fattarus/audio_fm_b0p01.wav

Carrier at 250 Hz, FM modulation at 125 Hz with β=0.01:
http://www.physics.smu.edu/fattarus/audio_fm_b0p01_pfm352p8.wav

Carrier at 250 Hz, FM modulation at 375 Hz with β=0.01:
http://www.physics.smu.edu/fattarus/audio_fm_b0p01_pfm117p6.wav

Carrier at 250 Hz, FM modulation at 1000 Hz with β=0.01:
http://www.physics.smu.edu/fattarus/audio_fm_b0p01_pfm44p1.wav