Welcome to Vibrationdata

Acoustics • Shock • Vibration • Signal Processing

March 2004 Newsletter

Aloha

I recently acquired a Marantz cassette recorder, which I am using to take some field recordings. Beginning with this issue, I will be presenting some of this data.

The image on the right is a wind chime in my backyard. It consists of five hollow tubes that behave as free-free beams in the engineering sense. The wind chimes produce a delightful melody in the E scale, although the presence of additional frequencies renders the resulting sound as somewhat atonal. The first article provides a sound and vibration analysis of the chimes.

The second article gives a sound analysis of a thunderstorm that occurred over my hometown earlier this month. The storm was welcomed given that Arizona has had a drought for several years.

I hope you enjoy the articles. As always, I appreciate your feedback.

Sincerely,

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Feature Articles

Wind Chime Sound & Vibration

by Tom Irvine

History

A number of cultures throughout history have enjoyed the pleasing sounds of wind bells and wind chimes. Widespread use of wind chimes can be traced to ancient China.

The Chinese became excellent metal workers, particularly in refining iron, around the year 1000 B.C. They began producing wind bells at this time for ritual ceremonies.

The use of wind chimes spread to Japan around 400 B.C. The Japanese used these chimes in Buddhist temples as well as in home gardens.

The Japanese produced a bronze wind bell called *dotaku*. They later developed a smaller and lighter wind chime called the *furin,* which were made from glass, metal or ceramics. The furin chimes were often hand painted.

The wind chimes enjoyed by western cultures today are typically made from rods of varying lengths suspended from a rack. This design became popular in the 19th century. This design is partly due to a musician who sought to improve the tone of the bells he played in an orchestra. Entrepreneurial Victorians, remembering the Japanese furin, popularized this design.

Author's Wind Chime

The wind chime model is "Cavernous Echoes" by Majesty Bells, as shown on the cover page. The vendor's brochure states that this is a five note wind chime hand-tuned to the scale of E. The material is anodized aluminum. The outer diameter is 1.25 inch. The chimes are hollow, with a wall thickness of 3/32 inch. The boundary condition is essentially free-free for vibration calculations. The condition is open-open for acoustic frequency.

The chimes have three wooden parts, which are from top to bottom: the head, the striker, and the wind catcher.

Experiment

Assume that the wind chimes have three types of possible responses as shown in Table 1. Furthermore, each type has higher modes. One of the objectives is to determine which modes type or types produce the chimes pleasing sound. The natural frequencies are calculated using textbook formulas.

In addition, the chimes also have a ring frequency corresponding to a breathing mode. This frequency is 50,540 Hz for each chime, since the chimes have a common diameter. This frequency is well above the upper frequency limit of human hearing, however.

The wind chimes were excited separately using the striker. The resulting responses were due to the bending modes in each case. Note that the bending mode is the only type in Table 1 that has non-integer harmonics, however. In this sense, wind chimes are atonal.

Frequency Response Data

The response data is summarized in Table 2. The musical note is the nearest note to the measured frequency.

The sequence: E, F#, G#, A, B, represents the first five tones of the E major scale. The complete E major scale contains this sequence plus C# and D#.

The second natural frequency of each chime represents a note in the E scale, as shown in Table 2.

Table 1. Wind Chime Fundamental Frequencies

Chime	Length (inch)	Vibration Bending (Hz)	Vibration Longitudinal (Hz)	Acoustical Longitudinal (Hz)
1	34.69	238	2832	194
2	32.56	271	3017	207
3	30.69	305	3201	219
4	29.94	320	3281	225
5	28.19	361	3485	238

Table 2. Measured Frequencies and Nearest Musical Notes

Chime 1		Chime 2		Chime 3		Chime 4		Chime 5	
Freq (Hz)	Note	Freq (Hz)	Note	Freq (Hz)	Note	Freq (Hz)	Note	Freq (Hz)	Note
244	B	278	C	312	D	330	E	371	F#
663	E	753	F#	850	G#	890	A	1000	B
1272	D#	1441	F#	1625	G#	1700	G#	3031	F#
2050	C	2314	D	2600	E	2712	D#	4351	C#

Waterfall plots for each of the five chimes are given in Figures 1 through 5, respectively.

The vertical axis is the Fourier transform magnitude, which has an arbitrary scale factor. Each axis scale is linear.

The corresponding frequencies for each chime are given in the accompanying tables. The calculated frequency is the bending frequency. The measured frequencies have reasonably good agreement for the calculated frequency for each chime.

The waterfall plots show the relative difference in amplitude between the various natural frequencies within each chime.

The extent to which each mode is excited depends in part on the impact location of the striker against the chime.

Whether the manufacturer considered the complexity of nodal lines when designing the striker position is unclear.

The waterfall plots also show how the reverberation time varies between the natural frequencies. The fundamental frequency is the frequency with the longest reverberation time for each chime.

The peak amplitude response, however, may occur at the second or third natural frequency for a given chime.

Bending Mode Shapes

A geometry model of chime 1 is shown in Figure 6.

The first through third bending mode shapes are shown in Figures 7 through 9, respectively. The mode shapes are greatly exaggerated, with an arbitrary scale factor.

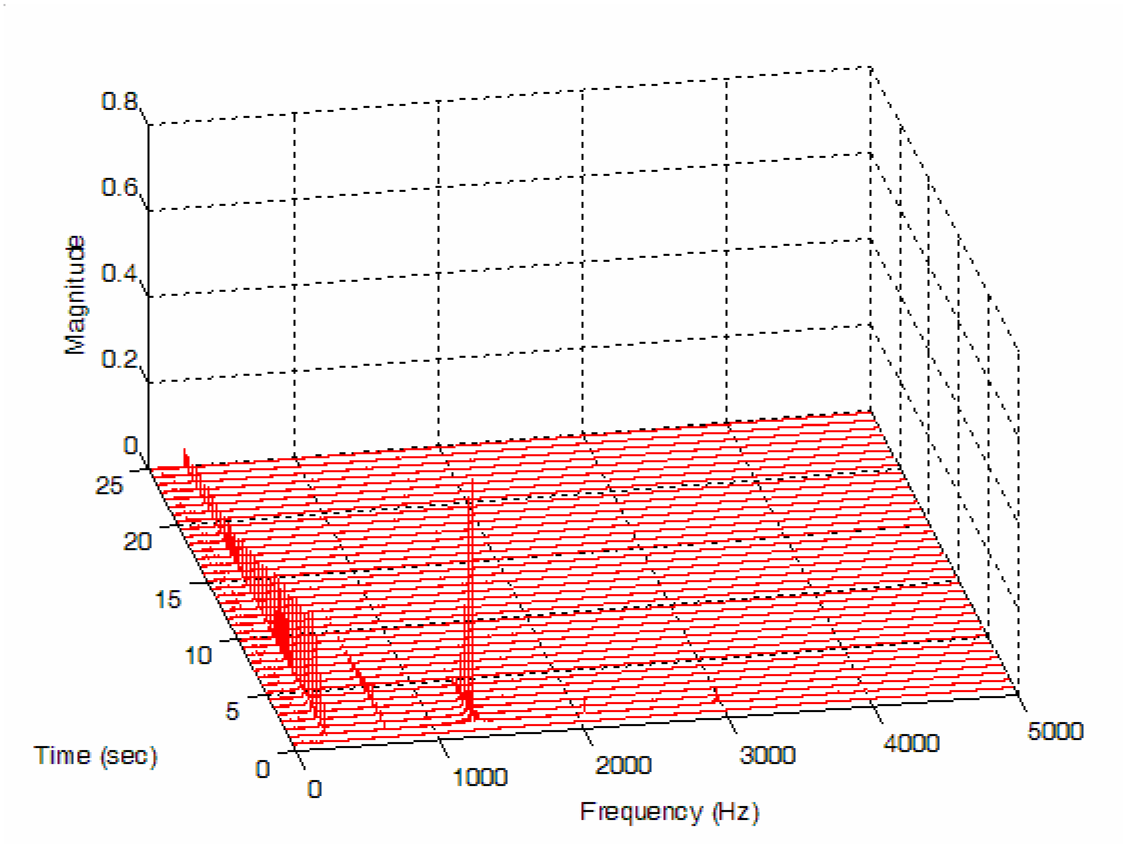

Figure 1. Chime 1 Sound Pressure Waterfall Plot

Table 3. Chime 1 Natural Frequencies

Mode	Calculated (Hz)	Measured (Hz)	Musical Note
1	238	244	B
2	657	663	E
3	1288	1272	D#
4	2127	2050	C

The peak amplitude response occurs at the third natural frequency. The fundamental frequency has a much longer reverberation time, however.

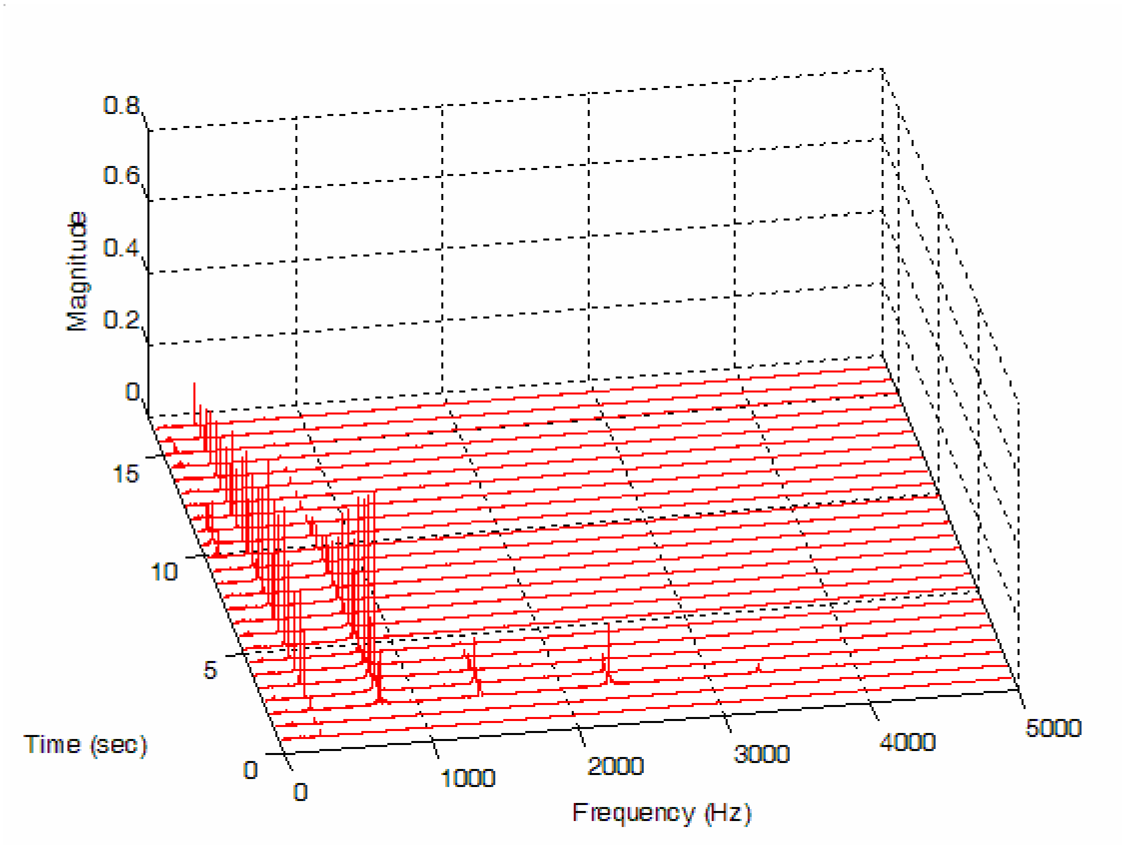

Figure 2. Chime 2 Sound Pressure Waterfall Plot

Table 4. Chime 2 Natural Frequencies			
Mode	Calculated (Hz)	Measured (Hz)	Musical Note
1	271	278	C
2	746	753	F#
3	1462	1441	F#
4	2414	2314	D

The first and second natural frequencies dominate the response.

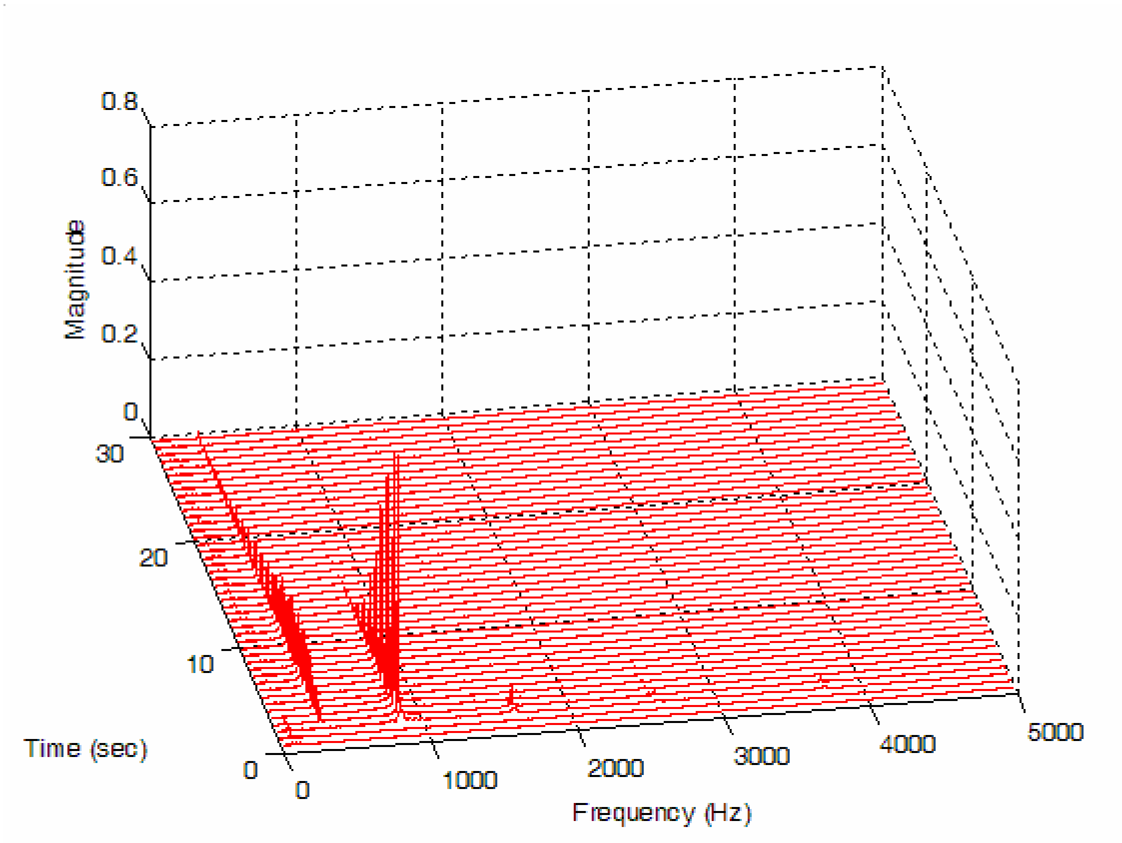

Figure 3. Chime 3 Sound Pressure Waterfall Plot

Table 5. Chime 3 Natural Frequencies			
Mode	Calculated (Hz)	Measured (Hz)	Musical Note
1	305	312	D
2	840	850	G#
3	1646	1625	G#
4	2718	2600	E

The second natural frequency clearly has the highest amplitude response.

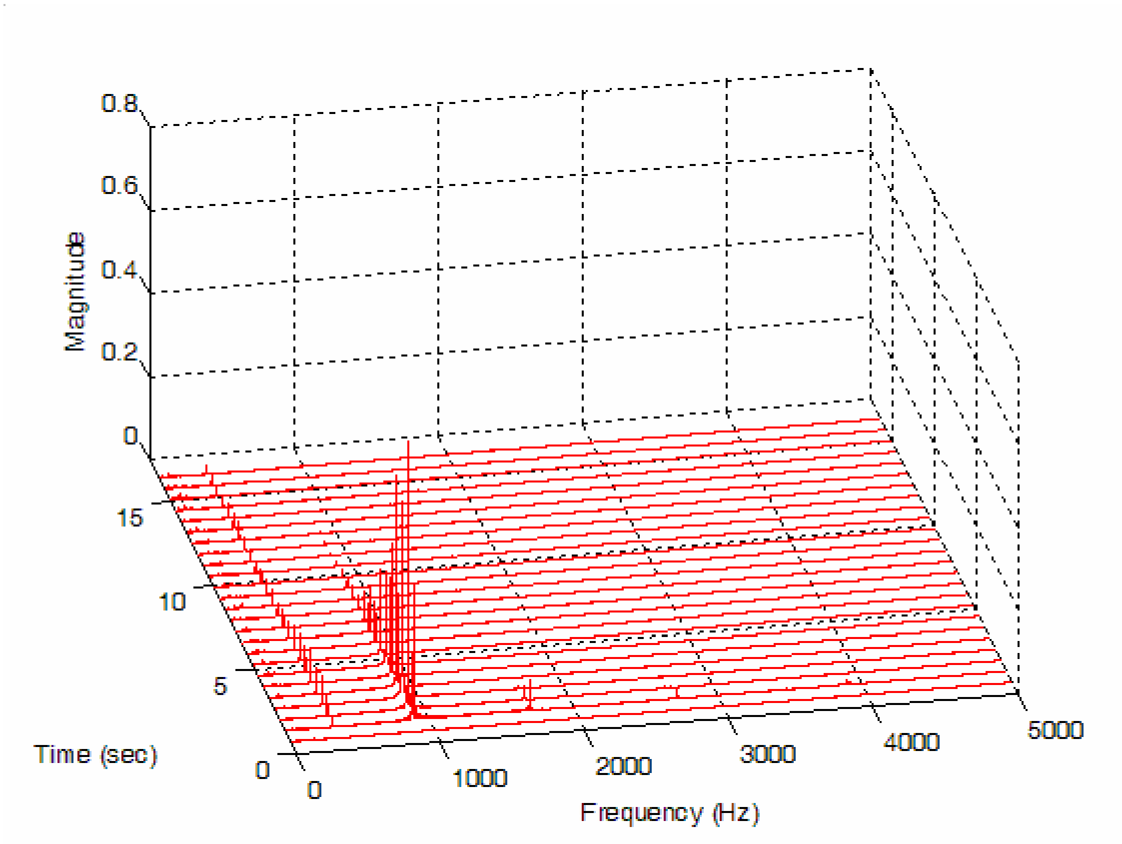

Figure 4. Chime 4 Sound Pressure Waterfall Plot

Table 6. Chime 4 Natural Frequencies			
Mode	Calculated (Hz)	Measured (Hz)	Musical Note
1	320	330	E
2	882	890	A
3	1729	1700	G#
4	2855	2712	D#

The second natural frequency clearly has the highest amplitude response.

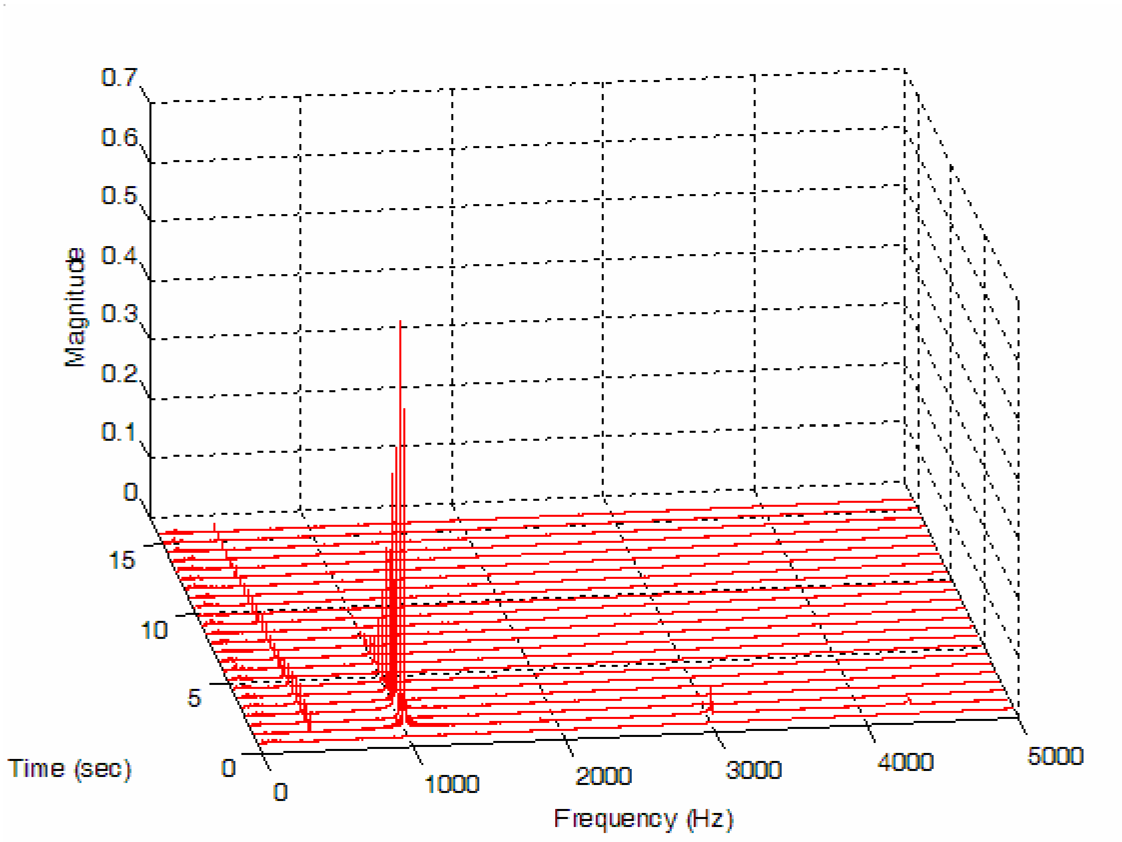

Figure 5. Chime 5 Sound Pressure Waterfall Plot

Table 7. Chime 5 Natural Frequencies			
Mode	Calculated (Hz)	Measured (Hz)	Musical Note
1	361	371	F#
2	995	1000	B
3	1950	3031	F#
4	3221	4351	C#

The second natural frequency clearly has the highest amplitude response, as was the case for the previous two chimes.

Figure 6. Chime 1, Undeformed Model

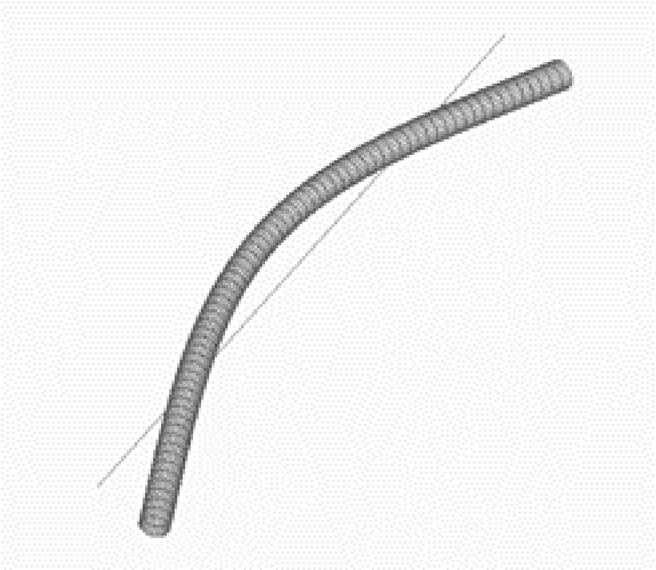

Figure 7. Chime 1, First Bending Mode

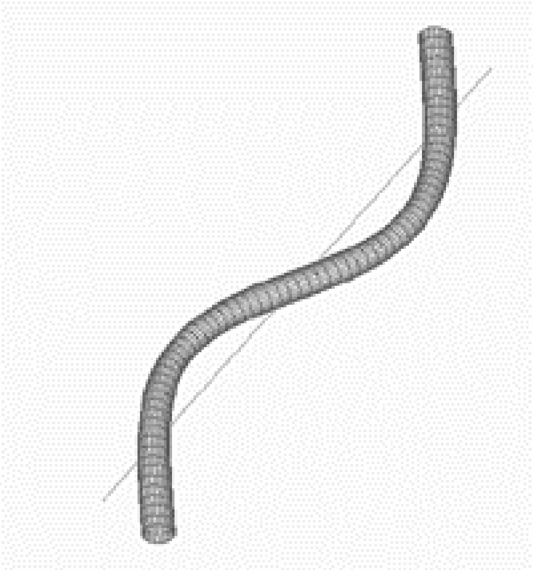

Figure 8. Chime 1, Second Bending Mode

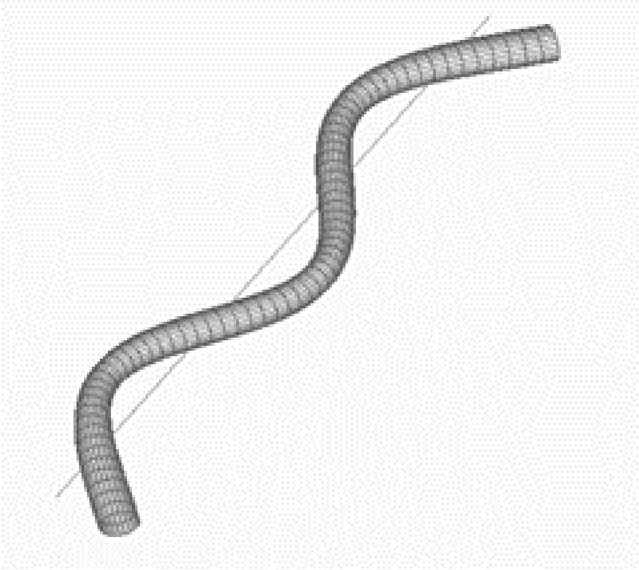

Figure 9. Chime 1, Third Bending Mode

Thunderstorm Sounds

Figure 1. Hail on the Author's Front Porch

Introduction

Lightning is a discharge of electrons from cloud to cloud, or from cloud to ground. The electrons strike adjacent air molecules. These violent collisions produce heat which rapidly expands the surrounding air. The air temperature may be near 50,000 degrees Fahrenheit

Furthermore, the air molecule expansion rate is greater than the speed of sound. The air molecules expand and then contract. This action produces shock waves, which are heard as a loud thundering noise. The shock waves may be considered as a sonic boom effect.

Nearby lightning strikes produces thunder with a loud but short cracking noise.

Distant strikes provoke a long, low rumble. For these strikes, the sound waves reflect off the ground, tall buildings, mountains, and clouds. This series of reflections causes a rumbling sound.

Additional rumbling noise occurs because sound is generated from all points along a lightning bolt, which may be as long as 1 mile, or 1.6 km. The sound waves originating from various points may reach the observer at different times. The resulting delays depend in part on the geometry of the bolt. The sound field is further complicated by any forks in the lightning.

All lightning strikes generate sound. The strike may be so far away, however, that the sound is attenuated to an inaudible level before it reaches an observer.

Thunder Data

A brief thunder and hailstorm occurred in Mesa, Arizona, at 6:30 pm, on March 4, 2004. A waterfall plot of a rumbling thunder burst from this storm is shown in Figure 2. The amplitude is linear, but the scale factor is arbitrary.

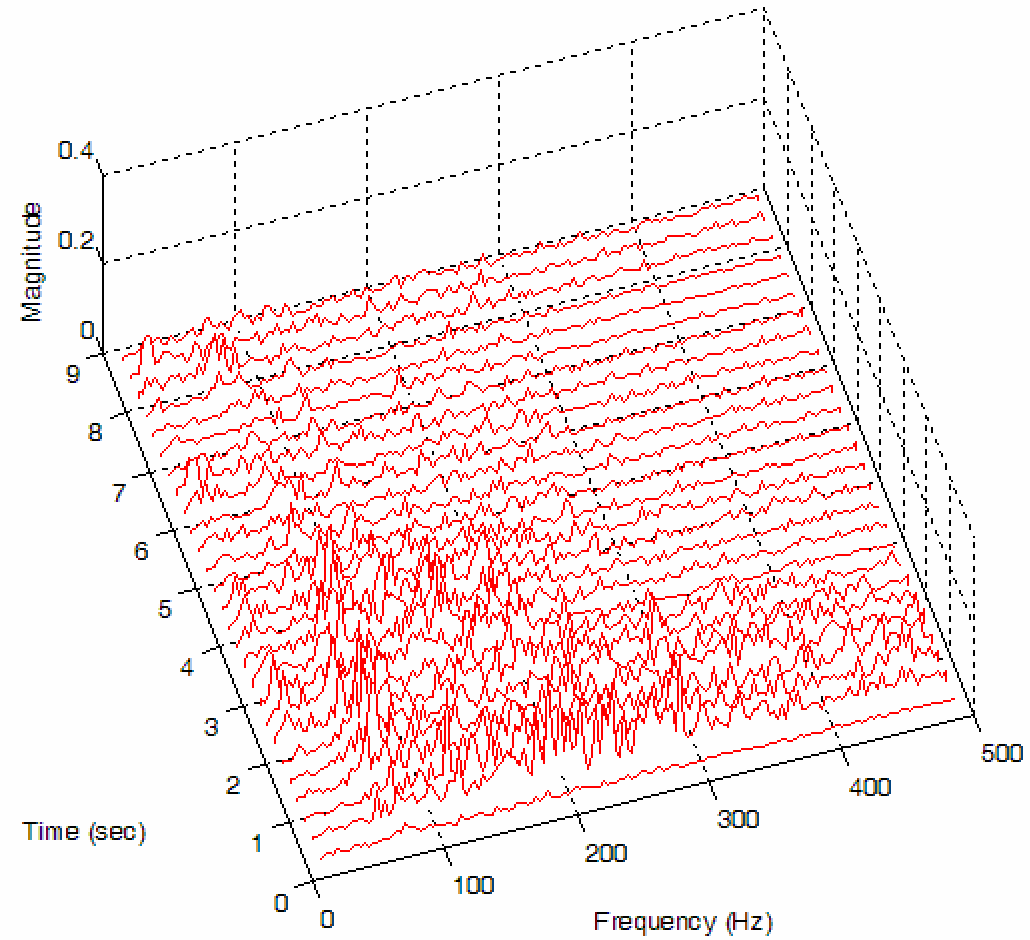

Figure 2. Thunder Rumbling, Sound Pressure Waterfall Plot

The waterfall plot shows that energy at lower frequencies tends to have a longer reverberation time than the energy at higher frequencies.

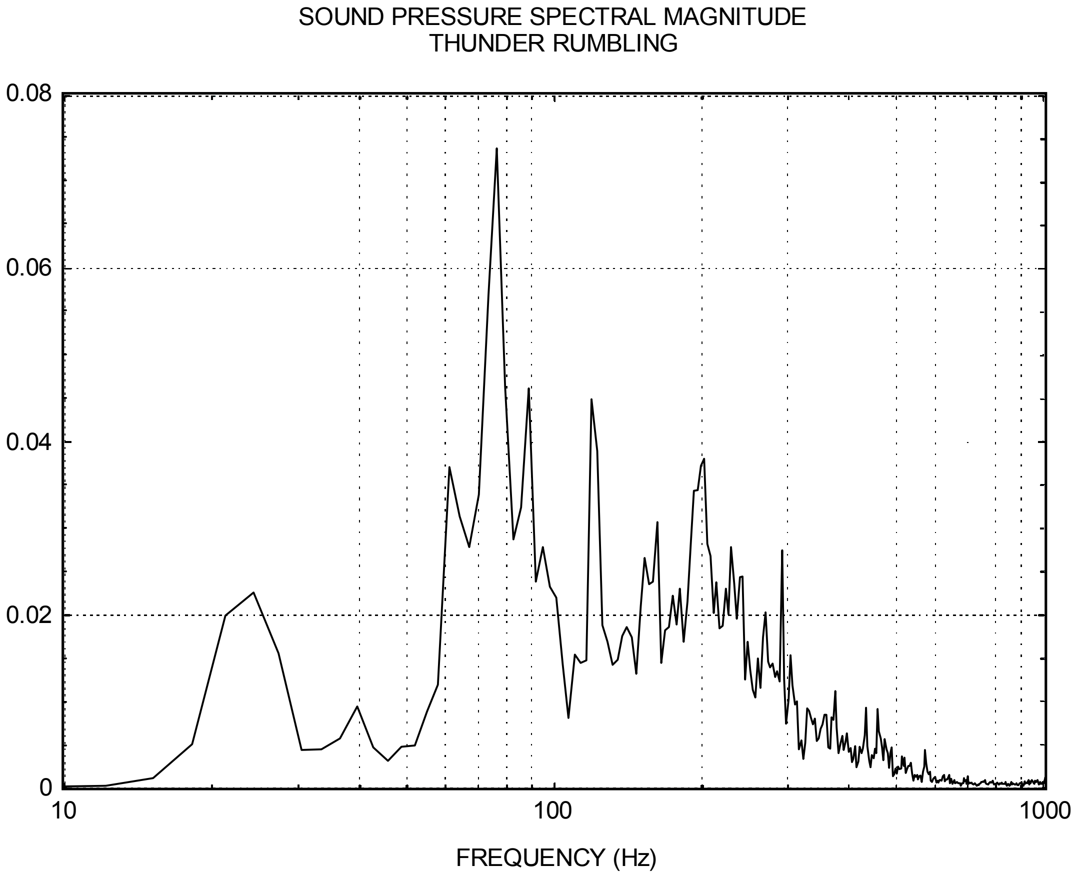

Figure 3. Thunder Sound Pressure

The spectral function in Figure 3 covers the complete duration of the thunder rumbling. Note that the recording system had some roll-off below 50 Hz. A significant amount of the sound output may have been infrasound, below 20 Hz which is the lower frequency limit of human hearing. The highest peak occurs at 76 Hz. The significance of the frequency remains an area for future investigation.

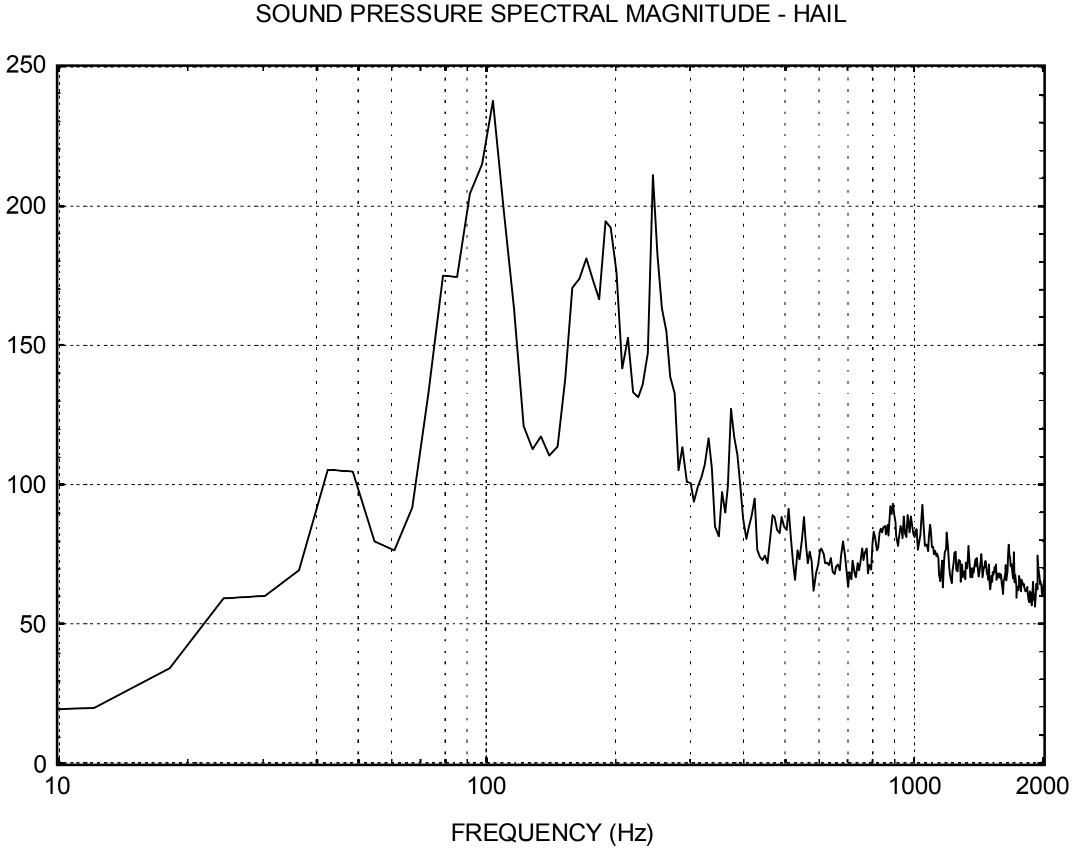

Figure 4. Hail Sound Spectra

Hail Data

The thunder and lightning were followed by a brief hailstorm, shown in Figure 1. The hailstones were about the size of marbles. A sound spectral function of the hailstorm is shown in Figure 4. The amplitude is again linear, but the scale factor is arbitrary.

The spectral peaks between 100 Hz and 300 Hz in Figure 4 may be largely due to the effect of the hail striking the sheet metal surfaces of the author's 1993 Ford Taurus, which was parked in the driveway.