

# Welcome to Vibrationdata

Acoustics • Shock • Vibration • Signal Processing

October 2004 Newsletter

## Greetings, Fellow Earthlings

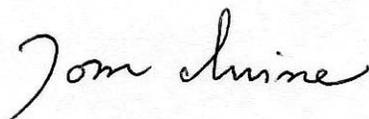
The Earth is a lively, vibrant sphere. Earthquakes, thunderclaps, exploding bolides, snapping shrimp, and seiches are examples of natural sound and vibration sources, which have been presented in previous newsletters.

The current newsletter adds the “Earth’s Hum” to this list. The frequency of this hum is about 16 octaves below the musical note middle C.

The second article discusses bell acoustics by presenting data from a bell at the Hall of Flame Fire Museum, Phoenix, Arizona.

One source states that “The bell is more complex acoustically than any other vibrating body intended for musical purposes.” The data from the museum bell appears to confirm this, particularly in terms of its beat frequencies.

Sincerely,



Tom Irvine  
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## Feature Articles



### The Earth’s Hum



### Bell Acoustics



The Earth's Hum is driven by Ocean Storms. Image courtesy of Primofish

### **The Earth's Hum** By Tom Irvine

The fundamental frequency of the Earth is 309.286 micro-Hertz, as mentioned in the February 2002 Newsletter. This is equivalent to a period of approximately 54 minutes. In addition, the Earth has myriad higher frequencies above the fundamental

In recent years, Japanese seismologists Naoki Kobayashi, Kiwamu Nishida and their colleagues discovered that the Earth emits an enigmatic hum with a frequency between 2 and 6 milli-Hertz.

This hum is far below the threshold of human hearing, which is has a lower limit of approximately 20 Hz.

This hum is not associated with earthquakes. The Japanese team suggested as an alternative source that

variations in atmospheric pressure might drum on the surface of the ground, giving rise to the vibrations.

Barbara Romanowicz and Junkee Rhie, from the University of California at Berkeley, have performed a further study of this unusual phenomenon using seismometer data.

The measured energy was that of Rayleigh waves, which are a type of surface wave.

The two Berkeley researchers determined the hum's direction of travel on each of 60 earthquake-free days that the Earth experienced in one year.

The hum came mainly from the North Pacific Ocean during January and March. Then the source swapped to the

southern oceans around Antarctica, before shifting north again in October. Therefore, the hum appears to follow winter in each hemisphere, when ocean storms are at their worst.

The daily release of energy required to generate the hum is equivalent to a magnitude 5.8 to 6.0 earthquake.

Rhie and Romanowicz think some of the energy contained in powerful waves generated by ocean storms at mid-latitudes is transferred via infragravity waves to the seafloor, resulting in seismic Rayleigh waves.

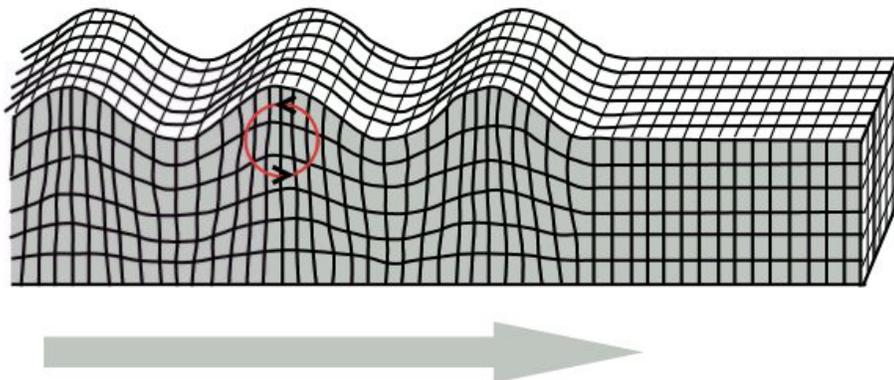
Ocean waves bouncing off the continents and continental shelves are likely creating longer and deeper waves that eventually reach the ocean floor, where they exert enough pressure to make the solid earth vibrate.



Ocean Waves by Japanese Artist Katsushika Hokusai

Their summary is that "The Earth's hum is generated by the interaction between atmosphere, ocean and seafloor."

## Rayleigh Wave



Rayleigh waves travel along the surface of the Earth.

Rayleigh waves produce retrograde elliptical motion. The ground motion is thus both horizontal and vertical. The motion of Rayleigh waves is similar to the motion of ocean waves except that ocean waves are prograde.

## Bell Acoustics by Tom Irvine



The bell at the Hall of Flame Fire Museum, Phoenix, Arizona.

The rim diameter is 34 inches. The height is 22 inches. The material is cast steel.

### Introduction

Bells have been used for music, worship, and other purposes since ancient times.

Buddhist temples in ancient China used bells.

Temple bells in Japan are rung 108 times on New Year's Eve, corresponding to the Buddhist concept of 108 worldly desires that are driven away by ringing the bell.

Bells are part of numerous Christmas carol lyrics, including Longfellow's, "I Heard the Bells on Christmas Day."

Big Ben is England's most famous bell, located in the clock tower of the Houses of Parliament in London.

The Liberty Bell in Philadelphia is a symbol of America's Independence.

Bells mounted on poles are used to mark the El Camino Real in California, which is a road connecting the Spanish missions.

Bells are also used for memorial services.

Gordon Lightfoot sang:

In a musty old hall in Detroit they prayed, in the "Maritime Sailors' Cathedral."

The church bell chimed 'til it rang twenty-nine times for each man on the Edmund Fitzgerald.

This song was not a mere ballad; it was a largely factual recounting of the sinking of the SS Edmund Fitzgerald in Lake Superior on November 10, 1975.

### Bell Materials

Bells have been made from copper and tin since the advent of the Bronze Age. The material often contains a small amount of lead, zinc, and even iron.

These proportions have ranged from approximately 70 percent copper and 30

percent tin (by weight) to as much as 90 percent copper and 10 percent tin.

As an alternative, some bells are made from cast steel.

Steel has a greater elastic modulus than bronze. The longitudinal wave speed in steel is higher than that in bronze. The natural frequencies in steel bells are thus higher than in bronze bells, given the same geometry. A steel bell tends to have a greater initial brilliance and loudness than the bronze one.

Bronze is still considered as the superior material, however. Bronze Bells have a deep melodious sound. A well-made bronze bell will hold its "hum note" for up to a minute after being struck because bronze is more dense than steel.

### Mode Shapes

A team of German students performed a finite element analysis of a bell and then compared the analytical results with actual measurements.

The finite element mode shapes are shown in Figure 1. The white areas also represent the undeformed mode shapes.

The first three modes are named as hum, prime, and tierce, respectively.

The nodal lines are the lines along which no translational motion occurs.

The hum mode has four nodal meridians and no nodal circles.

The prime mode has four nodal meridians and one nodal circle.

The tierce mode has six nodal meridians and one nodal circle. The nodal circle is near the midsection.

The quint mode also has six nodal meridians and one nodal circle. The nodal circle is located near the bottom rim, however.

### Beats

The ring of a bell tends to have significant beats. The beats cause periodic rises and falls in intensity.

The source of the beats is a lack of symmetry in casting, a result of irregularities in thickness and in the composition or homogeneity of the metal.

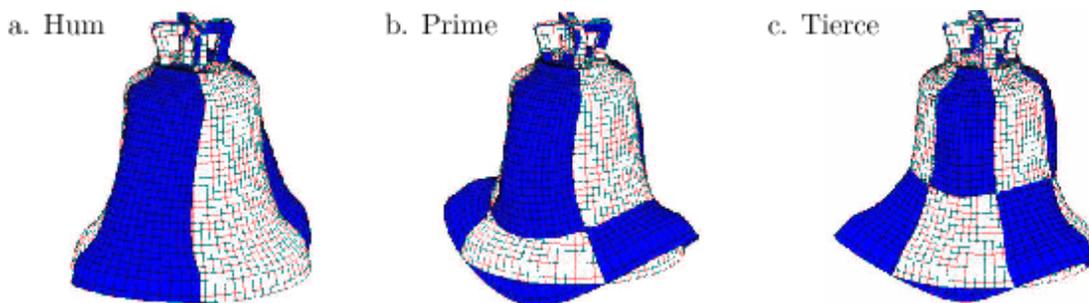


Figure 1. Bell Mode Shapes via Finite Element Analysis

Reference: Spiess, Lau, Wriggers, Schnedier, Bader, and Wiggenhagen; Analysis of Bell Vibration, Universities of Hamburg and Hannover, Germany.

## Hall of Flame Bell

| Frequency (Hz) | Nearest Musical Note | Tone Description  |
|----------------|----------------------|---|
| 392            | G                    | –   |
| 573            | D                    | Hum   |
| 733            | F#                   | Major third with respect to Hum   |
| 1200           | D                    | Fundamental, Prime, or Strike Note  |
| 1750           | A                    | Perfect fifth above the Prime. This is the quint.   |
| 2410           | D                    | One octave above Prime, or Nominal  |
| 3160           | G                    | A perfect fourth, up 2 ½ octaves above the Prime. It is also four octaves about the unnamed note at 392 Hz. |

The Hall of Flame Bell was rung in order to obtain measured data for this study.

The Hall of Flame Bell frequencies in Table 1 differ somewhat from those of a textbook bell. Specifically, a textbook bell would have a tierce, which is a minor third above the Prime. A tierce is unique to bells, producing a somewhat plaintive sound. The Hall of Flame Bell data, however, is missing the Tierce. A possibility is that the bell has a tierce that was not excited during the strike. This would occur if the clapper struck at a nodal line of the tierce mode. This possibility is somewhat hypothetical, however.

The note at 392 Hz does not have a descriptive label. It could represent a

mode of the clapper or headstock and frame assembly, but further investigation would be required to resolve this.

Furthermore, each frequency in Table 1 actually represents a cluster of two or more closely-spaced frequencies. The evidence is the beat frequency effect which is shown in the following bandpass filtered plots. The bulbous pattern is a result of the beats.

A waterfall FFT is shown in Figure 1. The prime note near 1200 Hz is spectral peak with the highest amplitude.

Bandpass filtered time history plots are shown in Figures 3 through 9. Each filtered plot represents one-third octave, with the noted center frequency.

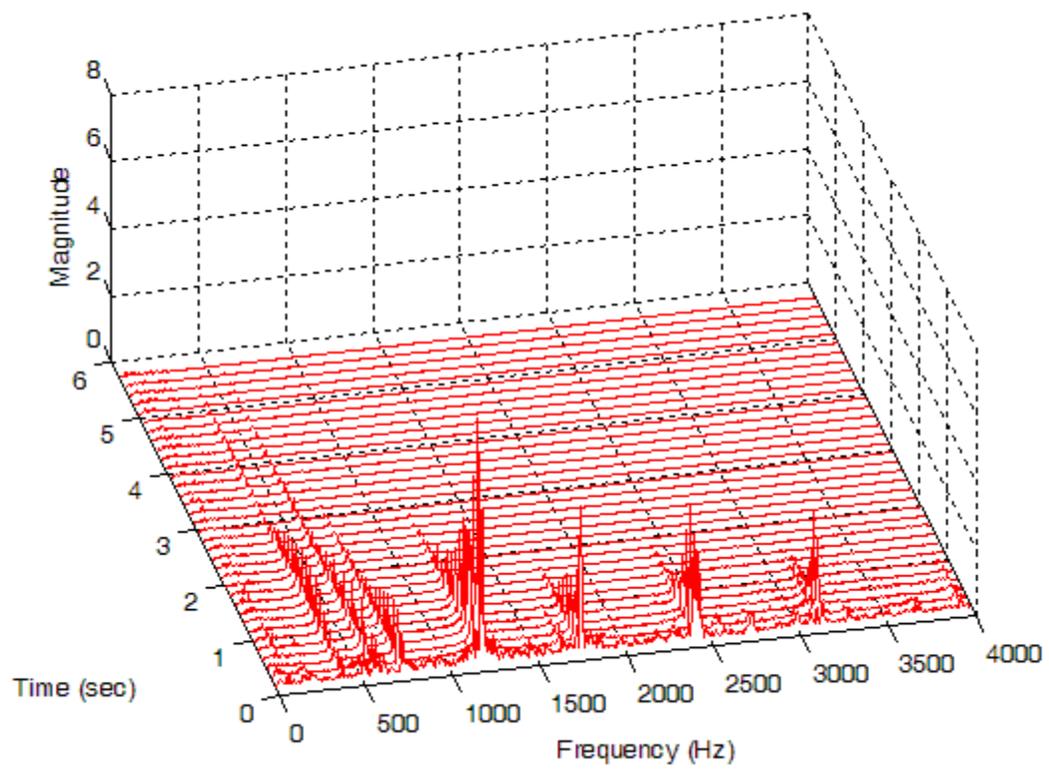


Figure 2. Sound Pressure Waterfall FFT Plot

BELL BANDPASS FILTERED CENTER FREQUENCY = 392 Hz

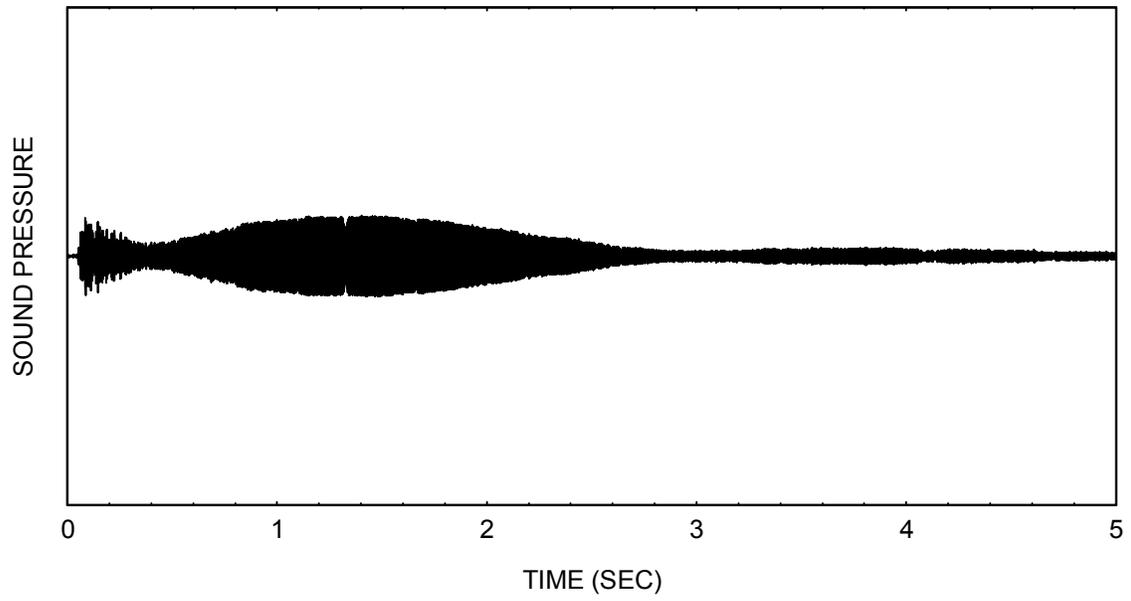


Figure 3.

BELL BANDPASS FILTERED CENTER FREQUENCY = 573 Hz

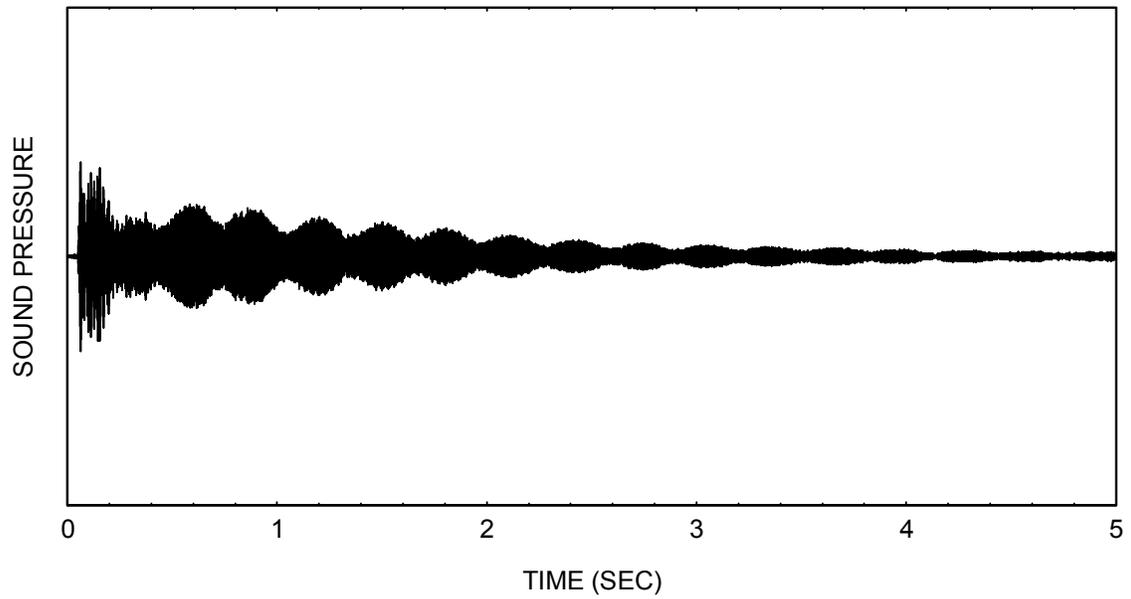


Figure 4.

BELL BANDPASS FILTERED CENTER FREQUENCY = 733 Hz

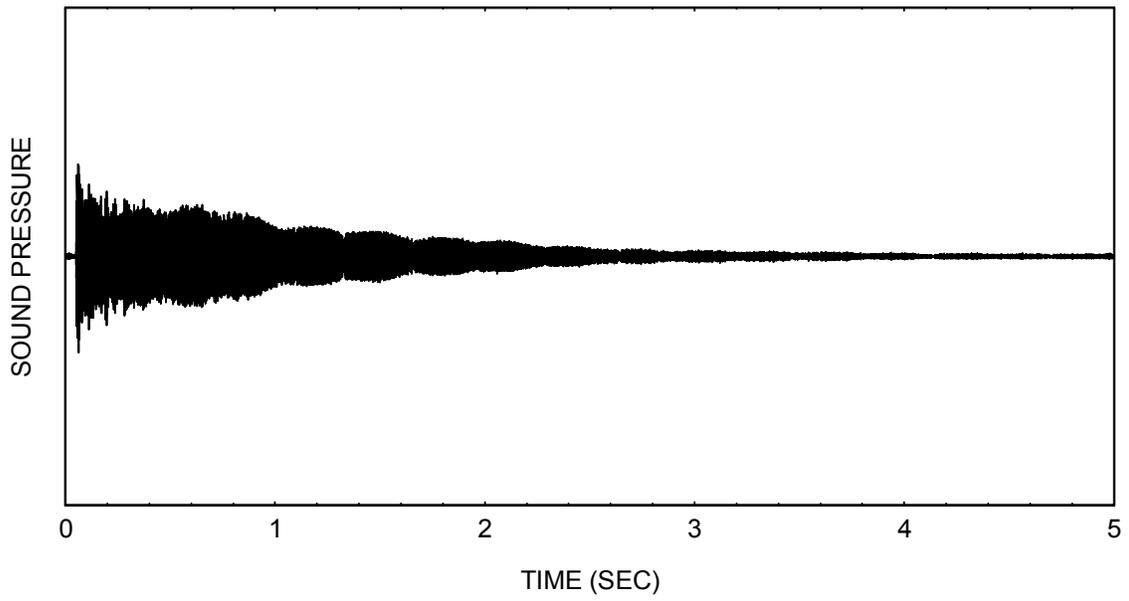


Figure 5.

BELL BANDPASS FILTERED CENTER FREQUENCY = 1200 Hz

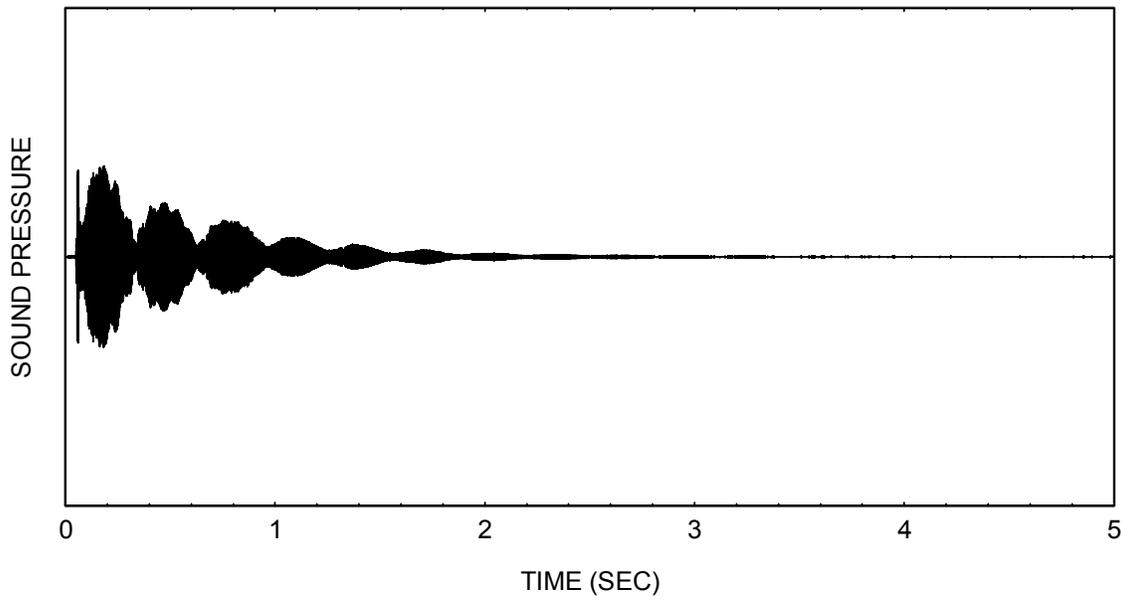


Figure 6.

BELL BANDPASS FILTERED CENTER FREQUENCY = 1750 Hz

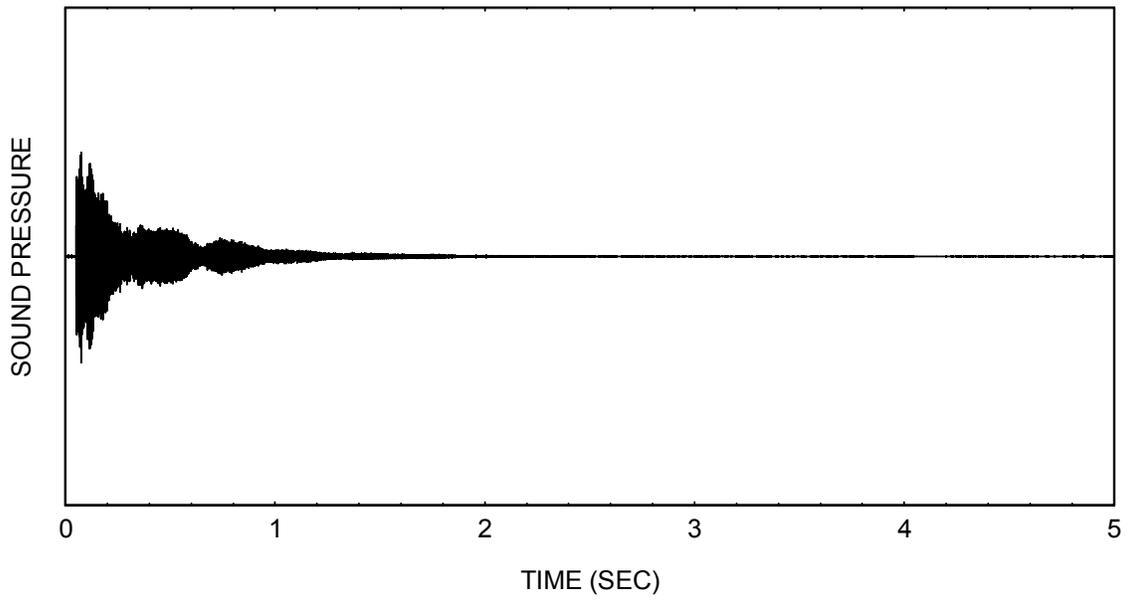


Figure 7.

BELL BANDPASS FILTERED CENTER FREQUENCY = 2410 Hz

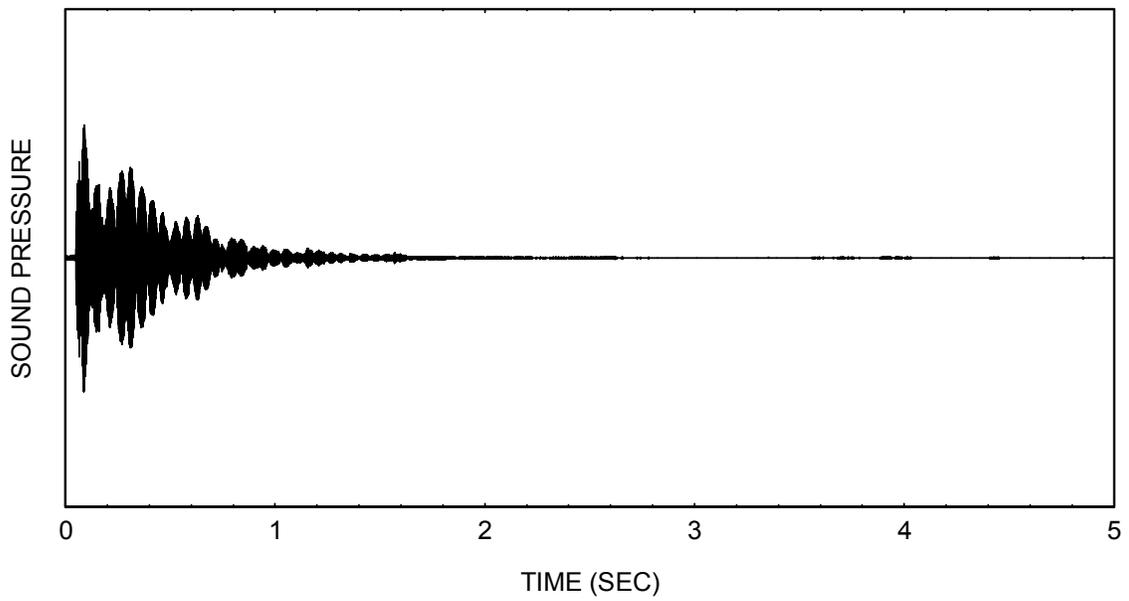


Figure 8.

BELL BANDPASS FILTERED CENTER FREQUENCY = 3160 Hz

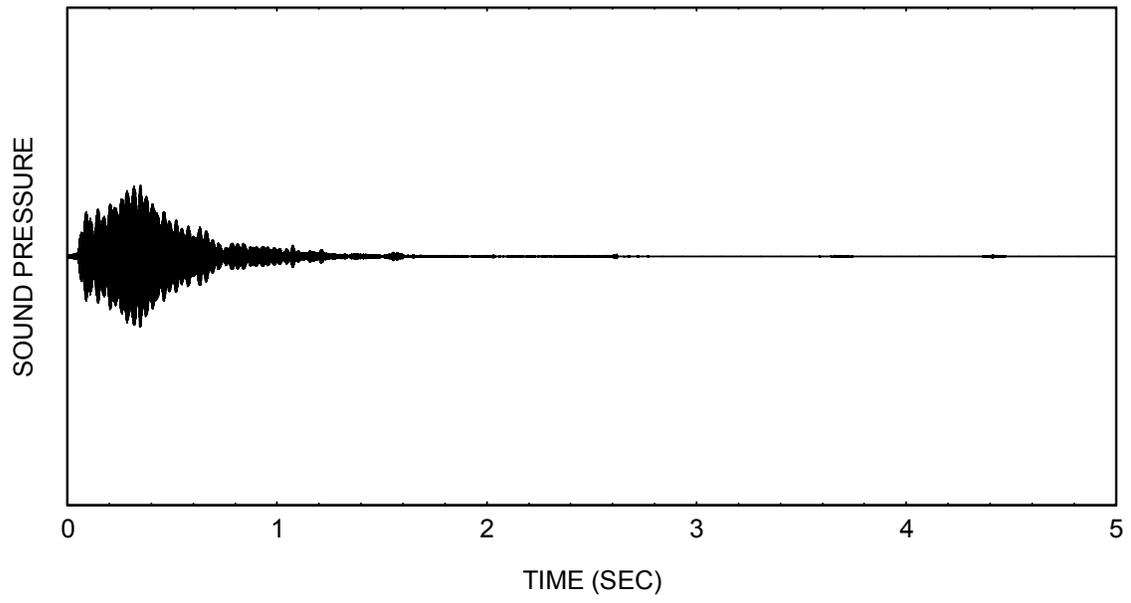


Figure 9.

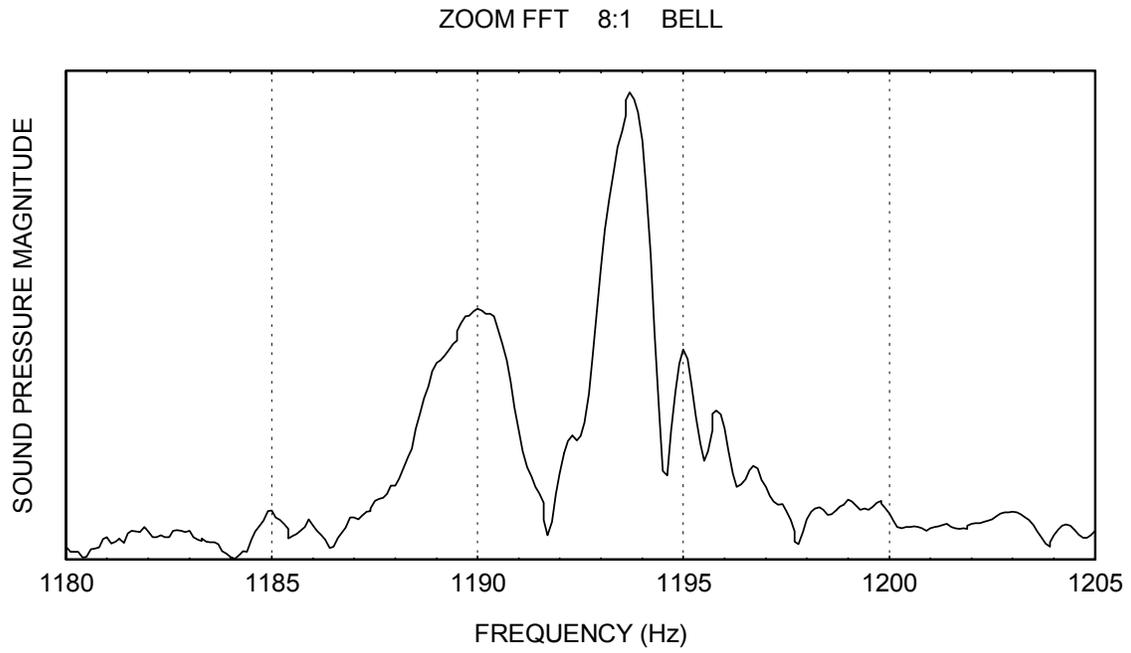


Figure 10.

The zoom FFT plot shows a number of peaks clustered just below 1200 Hz.

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I heard the bells on Christmas day  
their old familiar carols play.  
And wild and sweet the words repeat  
Of peace on earth, good will to men.  
And thought how, as the day had come,  
The belfries of all Christendom  
Had rolled along the unbroken song  
Of peace on earth, good will to men.  
Till ringing, singing on its way  
The world revolved from night to day,  
A voice, a chime, a chant sublime  
Of peace on earth, good will to men.  
And in despair I bowed my head  
“There is no peace on earth,” I said,  
“For hate is strong and mocks the song  
Of peace on earth, good will to men.”  
Then pealed the bells more loud and deep:  
“God is not dead, nor doth He sleep;  
The wrong shall fail, the right prevail  
With peace on earth, good will to men.”

- Henry W. Longfellow (1807-1882)

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No man is an island,  
Entire of itself.  
Each is a piece of the continent,  
A part of the main.  
If a clod be washed away by the sea,  
Europe is the less.  
As well as if a promontory were.  
As well as if a manner of thine own  
Or of thine friend's were.  
Each man's death diminishes me,  
For I am involved in mankind.  
Therefore, send not to know  
For whom the bell tolls,  
It tolls for thee.

- John Donne (1573-1631)