Hurricane Excitation of Earth Eigenmodes

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June 2005

Abstract

A non-conventional vertical seismometer, with good low-frequency sensitivity, was used to study earth motions in Macon, Georgia USA during the time of hurricane Charley, August 2004. During its transitions between water and land, the powerful storm showed an interesting history of microseisms and also generated more than half-a-dozen surprisingly coherent oscillations, whose frequencies ranged from 0.9 to 3 mHz.

1 Instrument

Shown in figure 1 is the instrument that was used for this study. It was once part of the WWSSN, and was manufactured by Sprengnether. This vertical seismometer, which uses a LaCoste zero-length spring, was modified by adding a fully-differential capacitive sensor [1]. The original sensor (Faraday law velocity detector) was subsequently used as an actuator to provide 'soft' force-feedback.

The instrument differs dramatically from conventional force-feedback seismometers in that the 'capacitor' of the sensor functions on the basis of area-variation rather then gap-spacing variation. Additionally, instead of using a single capacitor; an array of six elements has been used to increase the sensitivity; it is pictured in figure 2. Finally, the nature of the force-feedback is dramatically unconventional. Common 'force-balance' instruments use a network that operates with both differentiation and integration. The magnitude of the feedback force is so large as to render the mass of the instrument virtually stationary. In the present work, only integration is used, and the magnitude of the feedback force is much smaller.

2 Force Feedback

During the last seventeen years, the author has done much research concerned with the influence of internal friction on the damping of mechanical oscillators, including seismometers[2]. It is his opinion that strong force-feedback ('force-balance') seriously reduces low-frequency sensitivity as compared to a 'soft' feedback scheme. Thus, for the present experiments, only an integrator was used, as shown in figure 3. The power limitation of the operational amplifier used in the integrator prevents the actuator from being able to keep the mass(es) of the instrument nearly fixed, as in force-balance instruments. It is sufficiently large, however, to keep the instrument from 'going to the rails' as the result of thermal and other diurnal changes. The smaller level of feedback requires that the instrument be externally damped. This was done with eddy currents, using rare earth magnets held together by a ferrous frame (subsystem not pictured). The Q was estimated to be between 2 and 3, rather than the ideal value of 0.8. This is only important for high-frequency motions and not the low-frequency oscillations being presently reported.

3 Hurricane Season 2004

During the 2004 hurricane season, Florida was struck by several major hurricanes, four of which are shown in figure 4, along with their tracks through the state. The instrument described in this article recorded seismic data on all of these hurricanes except Ivan. We here report only on Charley, for which excitation of various mHz eigenmodes of the earth were quite detectable by the instrument; which was located in Macon, Georgia.

4 Florida crossing

Shown in figure 5 is a 36-hour compressed record, that begins as Charley approaches Charlotte county and which ends after Charley grazes the continental shelf off the coast from Savannah/Charleston.

4.1 Microseisms

The first obvious thing from figure 5 is the variation of 'noise'. It was at a higher level either side of that time when the eye of the storm was centered on the state. This is seen from figure 6 to result from changes in the level (and frequency character) of the microseisms generated by the hurricane.

Shown by the red vertical lines are the 'secondary' and 'primary' microseism peaks near 0.13 Hz and 0.25 Hz respectively. Three characteristics are obvious: (i) the level of both primary and secondary are lower when the eye of the storm is centered on the state, (ii) the width of the primary microseism peak increases with time, and (iii) the frequency of the primary peak shifts progressively toward higher values.

The decibel scale in figure 6 is one whose numbers are natural in terms of the analog to digital converter used, a 16-bit Dataq, model DI-700. To obtain the dB value relative to 1 V of the sensor output, one need only subtract 110.3 from the Dataq value.

5 Eigenmodes

Shown in figures 7 through 11 are spectra that highlight the readily observed eigenmodes that were excited by hurricane Charley. The times of their occurrence are indicated (with notation) by the five red-lines of figure 5.

In each of the indicated figures, three graphs are provided: (i) the top curve is the raw temporal data, (ii) the middle curve is what results after bandpass filtering of the raw data, using a hanning-windowed FFT. The size of the FFT, along with the amount of data compression (input averaging in Dataq terminology) is indicated in the bottom curve; which is the spectrum. The ordinate for the top and middle curves (unlabeled) is 'sensor output in volts', where the range can be determined from the printed numbers showing 'rail' values of the voltage. In the bottom graph the ordinate is in dB, where as noted earlier, conversion to the more common form is accomplished by subtracting 110.3. The frequency values of the bottom graph can be read from the abscissa numbers at the bottom.

The calibration constant for the sensor was not accurately measured for this work, even though the front-surface mirror used for such a calibration (optical lever technique) is visible in the picture of figure 2. The calibration constant is likely to be close to the value of 2000 V/m, which was measured during earlier similar experiments, approximately five years ago. The accurate estimate of magnitudes is presently of secondary importance.

6 Eigenmode excitation Mechanism

Hurricanes like Charley are enormously powerful storms that spread over a large surface of the earth. When they cross from water to land (or vice versa), they experience a signficant change in surface impedance. Because of the low-atmospheric-pressure of the eye, its passage across the impedance discontinuity will result in a dramatic forcing function to excite the land mass at that point into oscillation. The larger the size of the hurricane, the lower the frequency of the excitations that are possible.

To this author's knowledge, others have not observed these hurricane driven eigenmodes. This probably results from at least two factors: (i) inadequate low-frequency performance of conventional instruments, and (ii) the distance from source of excitation to the observer has been great. Macon, Georgia is ideally suited to the study of hurricanes that frequent the state of Florida, and the modified conventional seismometer is clearly well-suited to this type of measurement.

References

[1] R. D. Peters, "Symmetric differential capacitance transducer employing cross coupled conductive plates to form equipotential pairs", U. S. Patent No. 5,461,329 (1995). Online information at http://physics.mercer.edu/petepag/sens.htm

[2] see, for example (i) R. Peters, "Friction at the mesoscale", *Contemporary Physics*, vol. 45, no. 6, 475-490 (2004), and (ii) R. Peters, ch. 20 & 21, **Vibration and Shock Handbook**, ed. C. deSilva, CRC (2005).

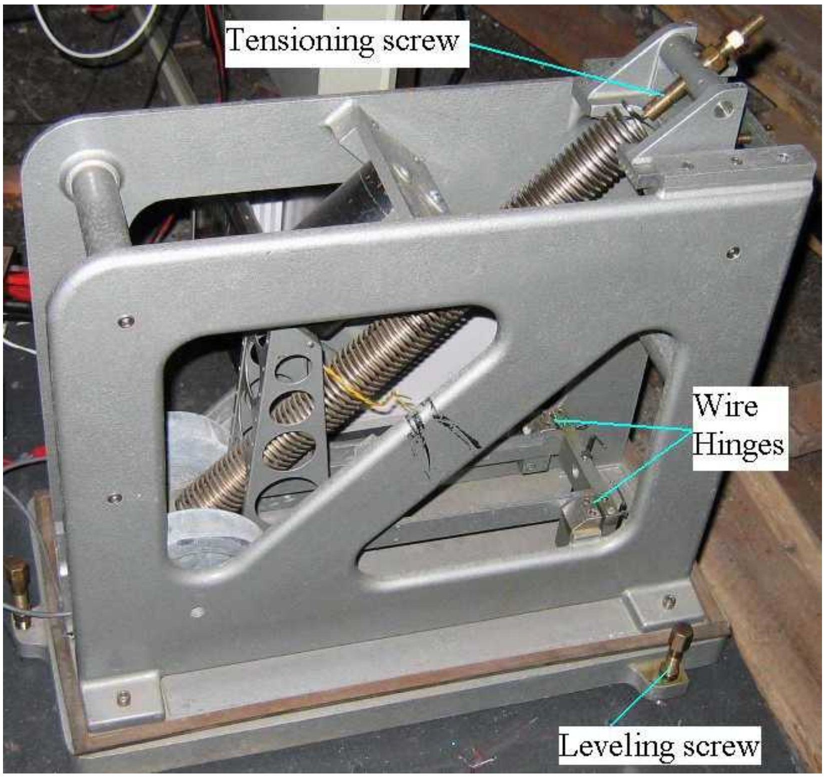


Figure 1: Photograph of the modified Sprengnether vertical seismometer.

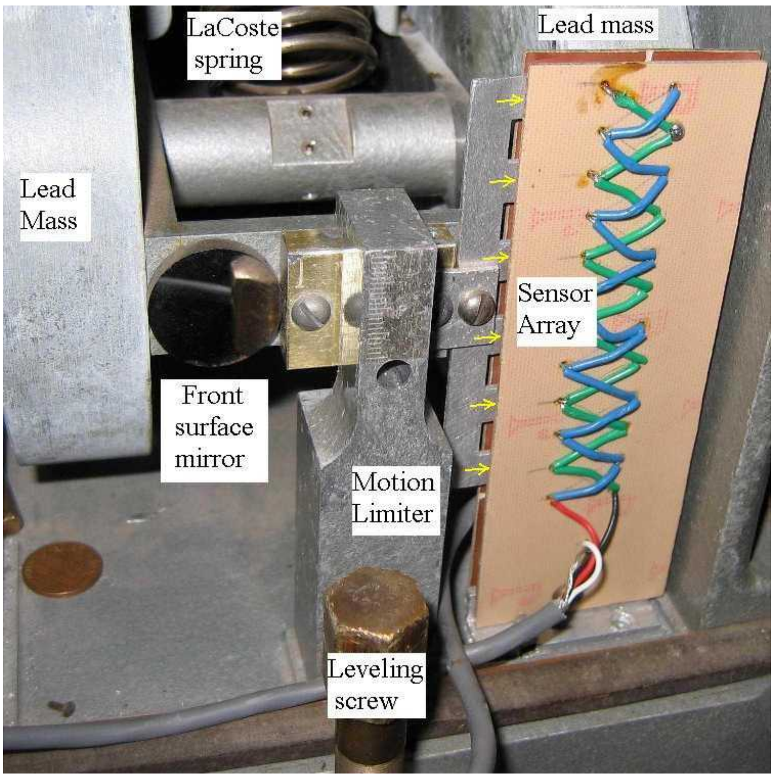
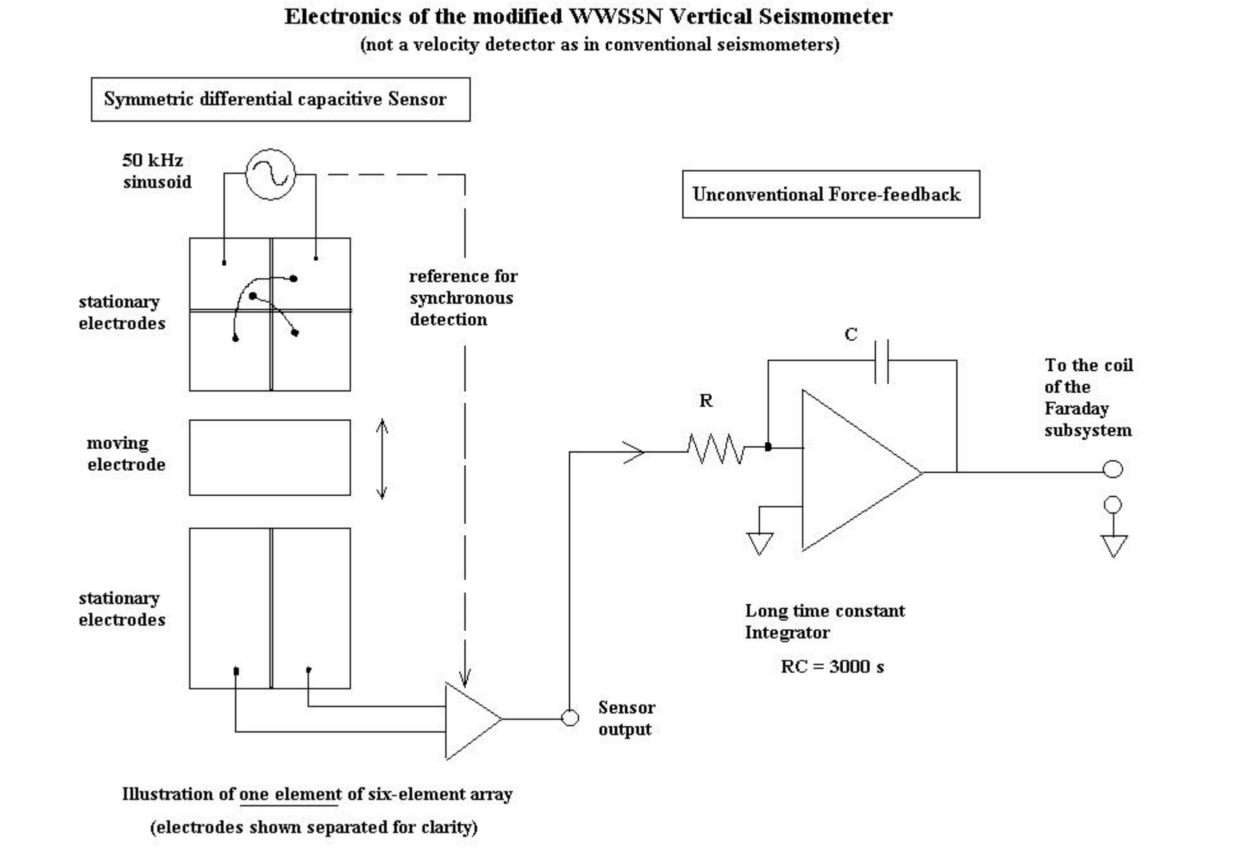


Figure 2: Fully-differential capacitive sensor array.



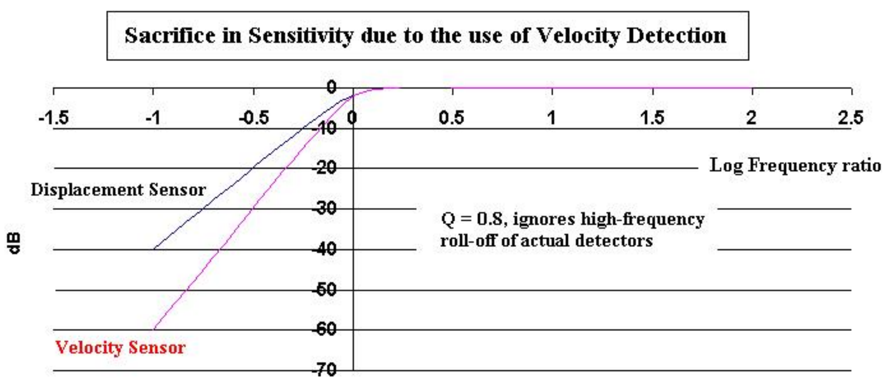


Figure 3: Electronics of the force-feedback (top); why velocity detection is not used (bottom).

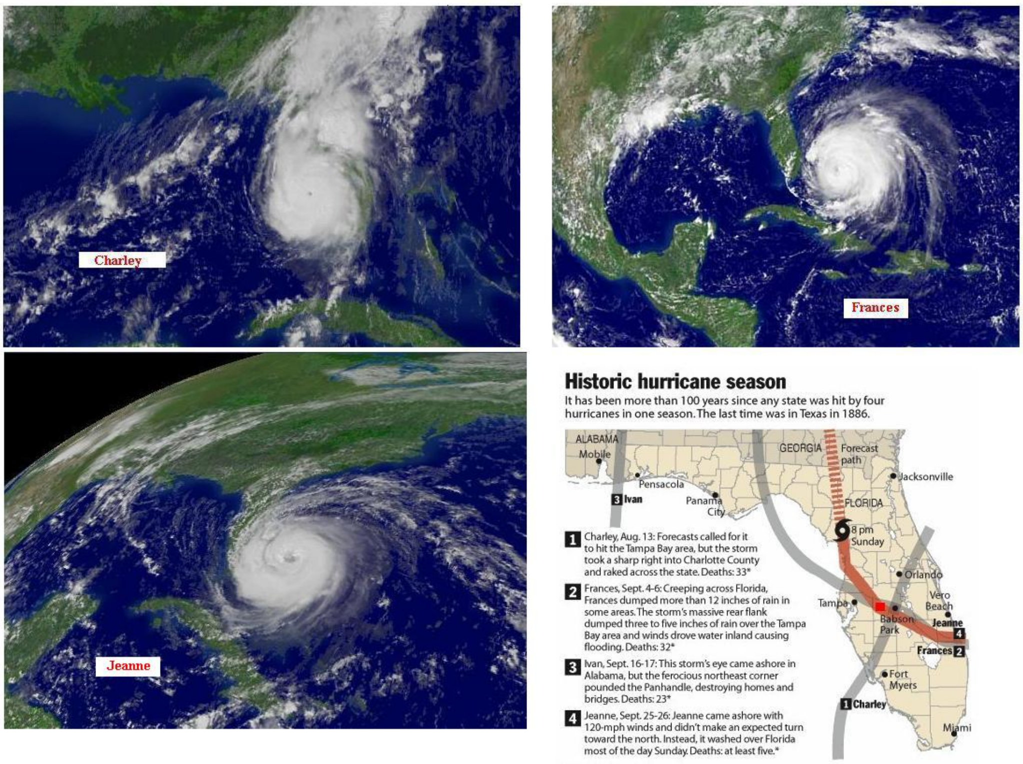


Figure 4: Some hurricanes of the 2004 season.

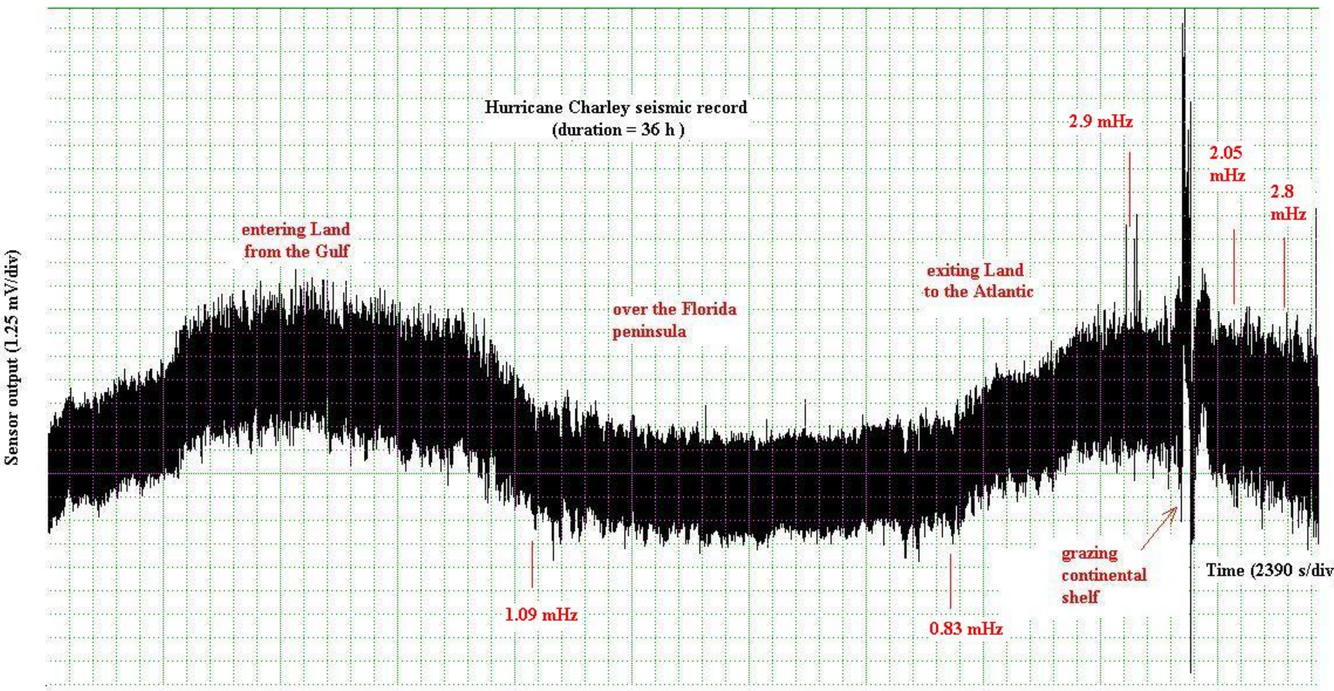


Figure 5: Seismicity of hurricane Charley, before and after crossing Florida.

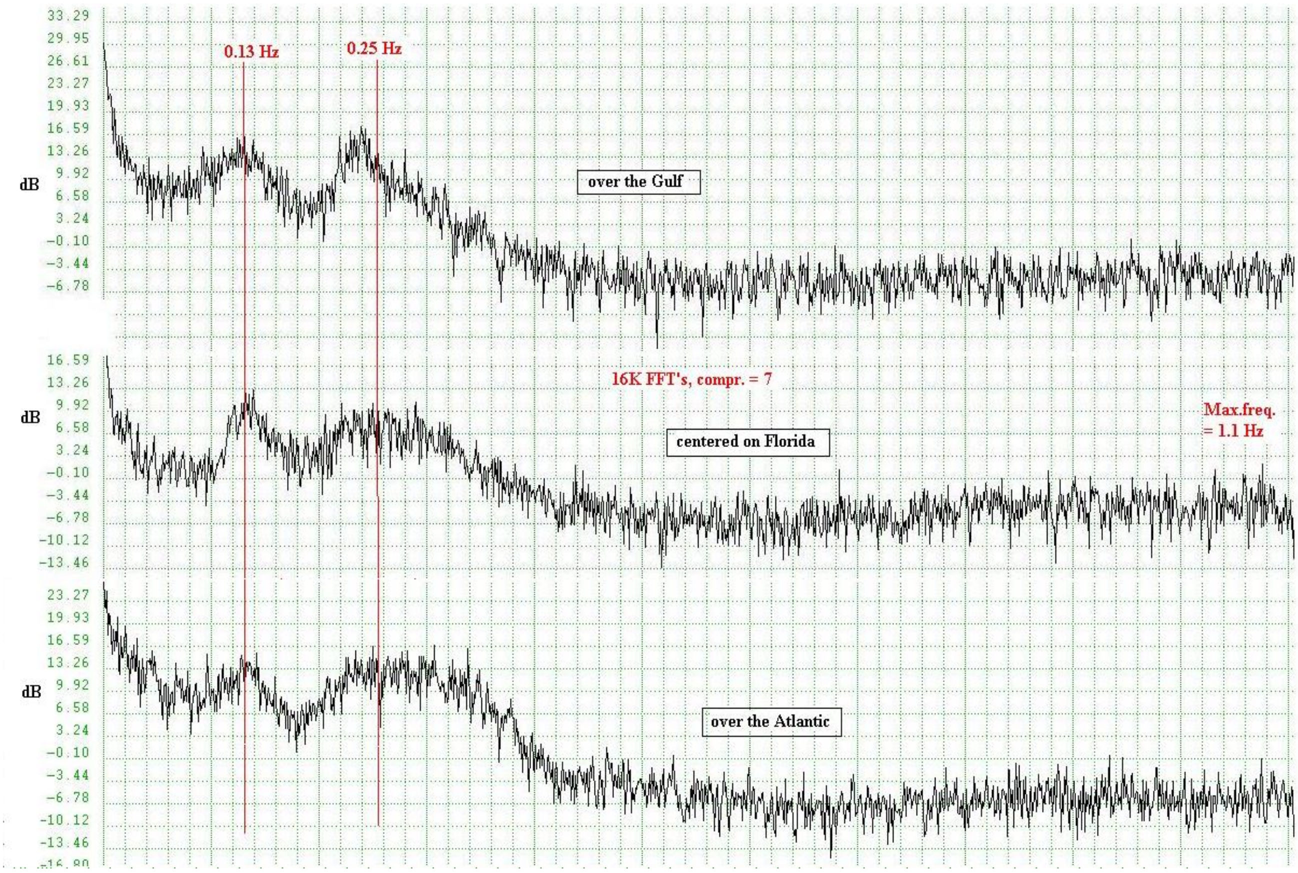


Figure 6: Spectra showing the microseism activity.

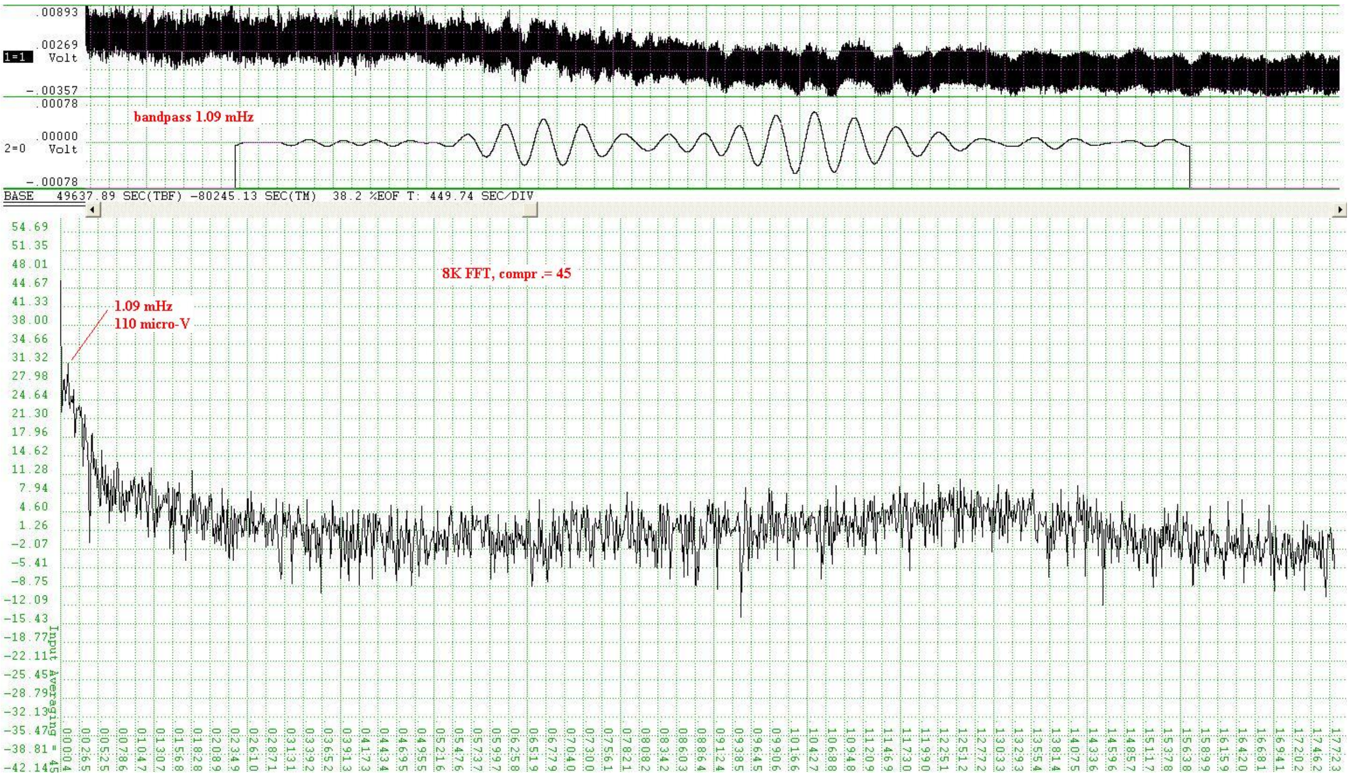


Figure 7: First indicated oscillation in figure 5.

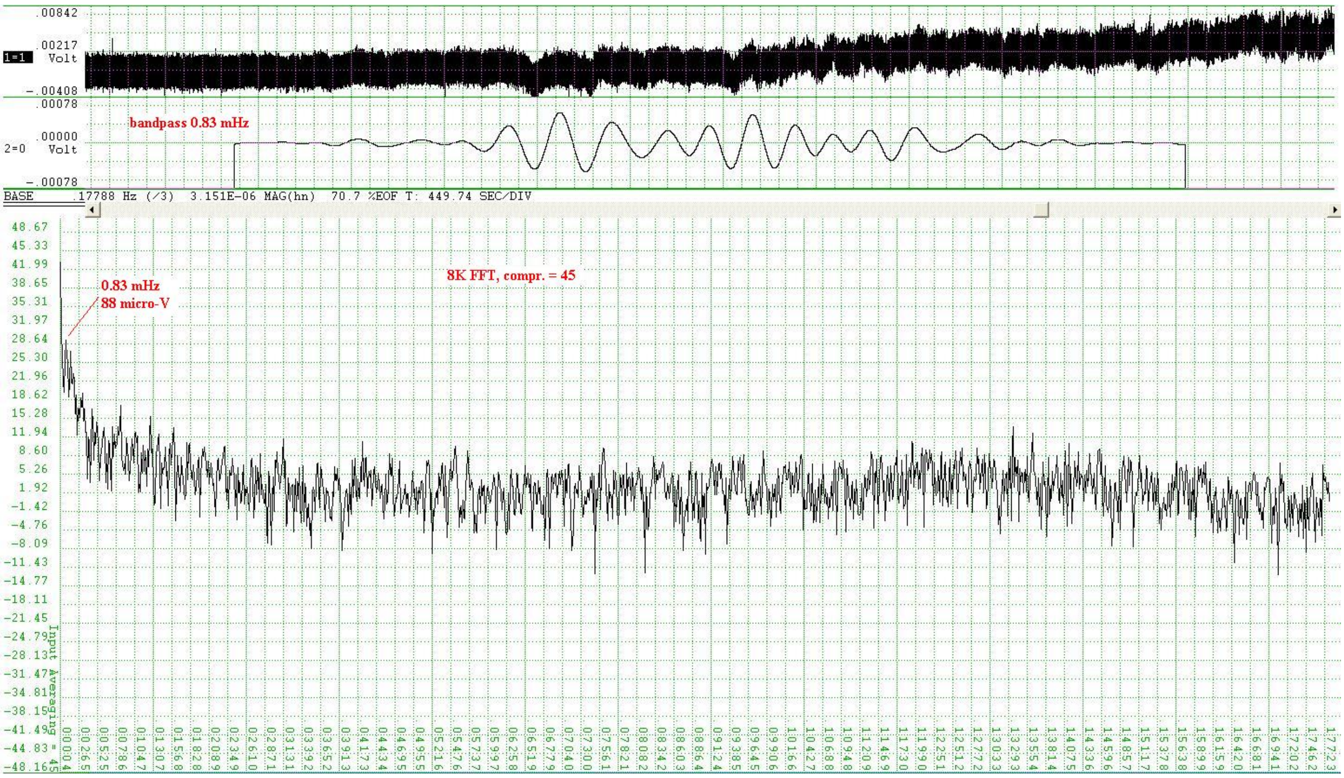


Figure 8: Second indicated oscillation in figure 5.

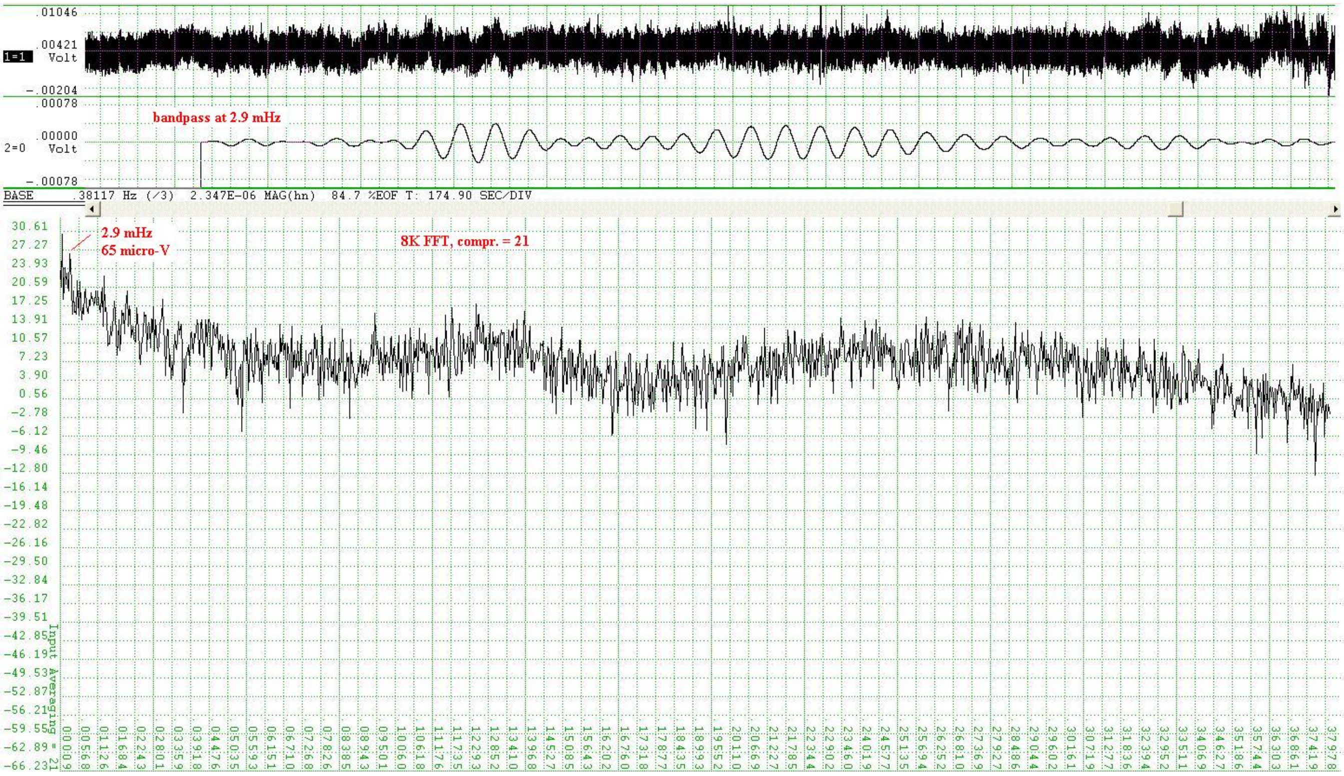


Figure 9: Third indicated oscillation in figure 5.

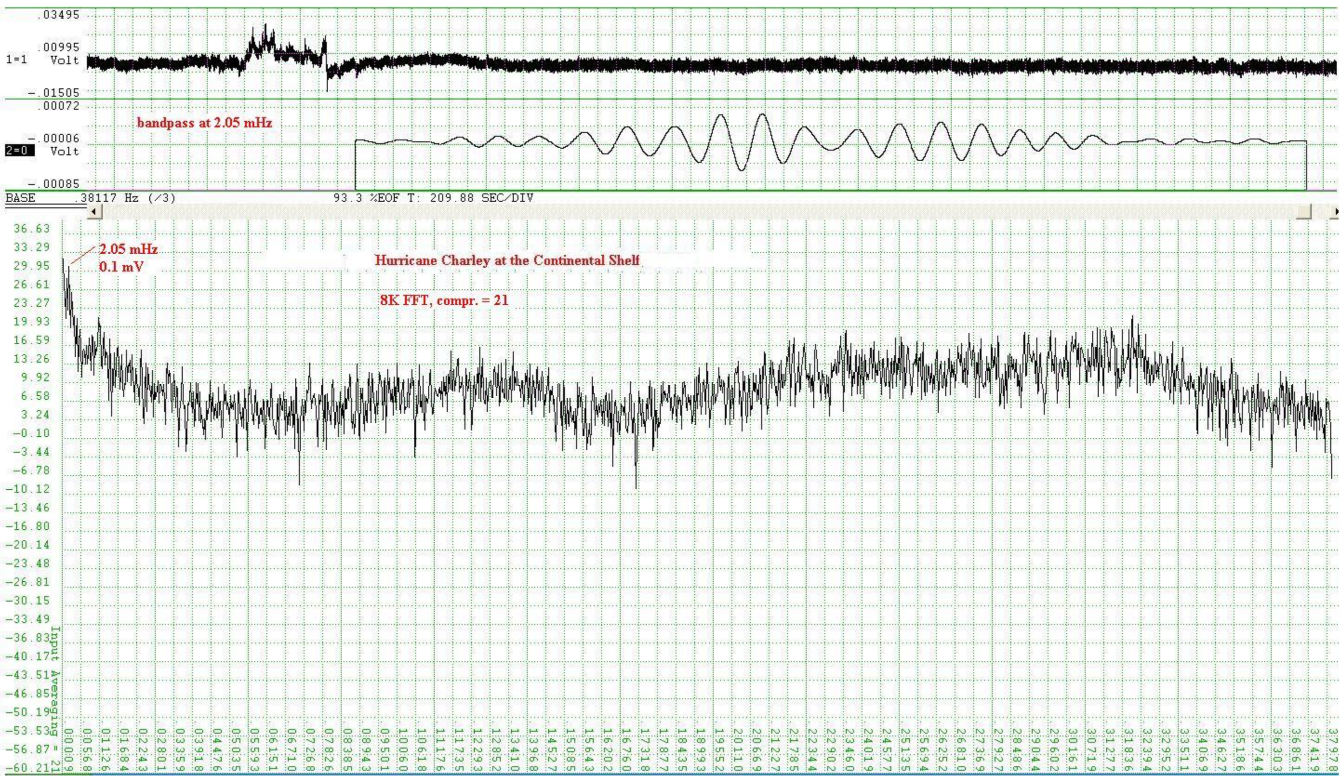


Figure 10: Fourth indicated oscillation in figure 5.

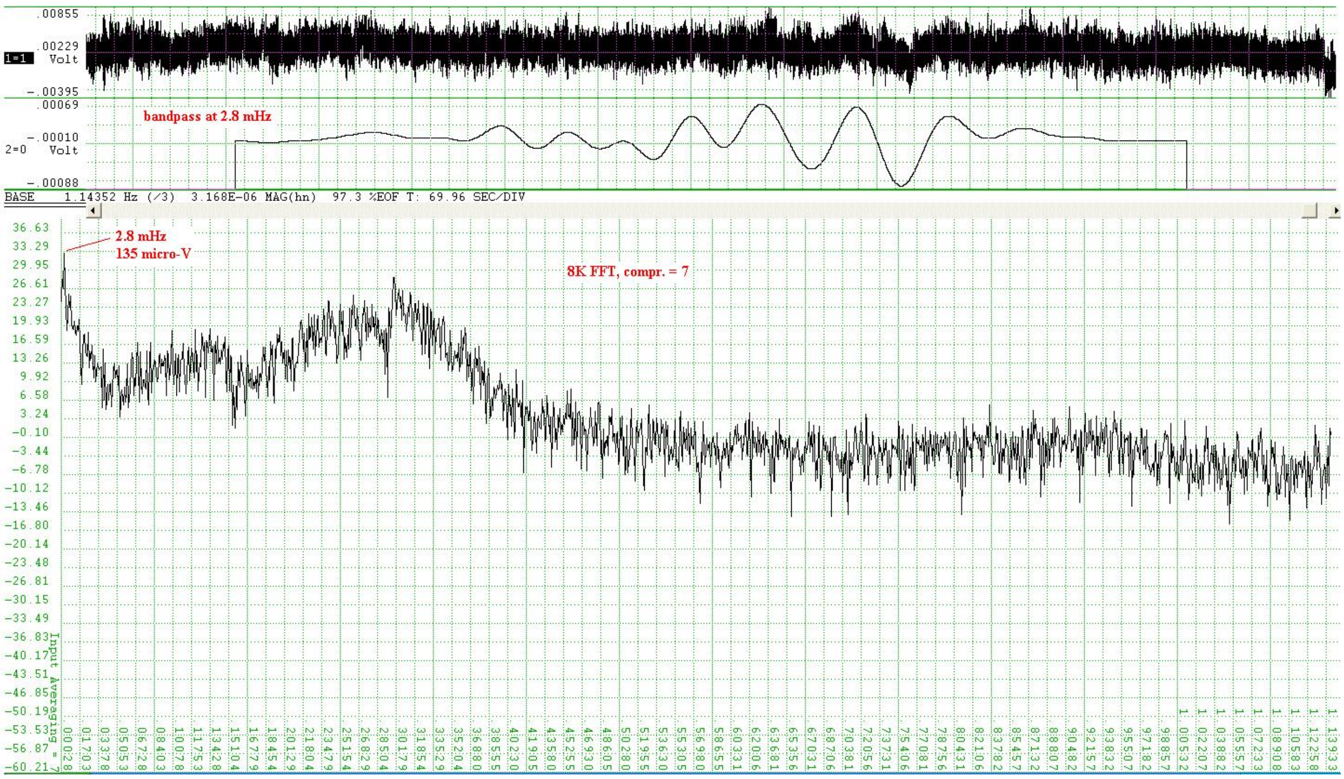


Figure 11: Fifth indicated oscillation in figure 5.