Vibration Sentry RT

Going Beyond the Instrument’s Resolution

Time/Date: 09:39:55 12/17/2012
Temperature: 25.2 deg C
User ID: Unit-15
Model: Vibration Sentry RT
Firmware_Revision: 1.0
Date of Birth: Thu, Dec 13, 2012 - 8:37 AM
Last Calibration: Thu, Dec 13, 2012 - 8:37 AM
Memory Depth (DD HH:MM:SS): 00 00:00:00 – 00 00:07:16
Fs: 3.2k Hz
N: 256
Cursor0: Z-Axis 256.25 -47.97
Window: Hanning
Weighting: Exponential
Avg Mode: RMS averaging
Nb Avg: 30

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1 Introduction

All instruments have a noise floor, the point at which the measured quantity is so small that the instrument is measuring mostly its internally-generated noise. However for some instruments, even though the information about the measured quantity is diluted within the noise, it is still there and can be extracted using the proper tools.

2 Where is that Signal?

In the case of the Vibration Sentry RT, the noise is mostly due to the quantization of the acceleration signal. When the signal to be measured becomes very small, individual quantization steps can be seen in the signal.

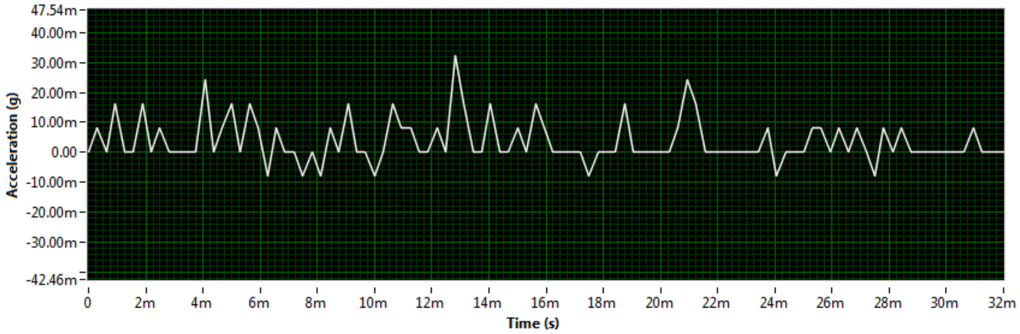


Figure 1

Figure 1 shows a portion of signal, sampled at *Fs* = 3.2 kHz, where the sensor is at rest. It is clear that the quantization step is 8 10^{-3}g, and the signal can only “jump” in multiples of the quantization step.

This type of signal is typical of the output of an Analog to Digital Converter when the measured signal is at, or below, the instrument’s resolution.

When a signal to be measured is smaller than the quantization step it is natural to think that the signal is lost within the instrument’s noise. However the signal is often still present within the noise, and it can be detected, extracted and even measured with a remarkable precision.

Most techniques used to detect a signal buried in noise rely on long-term correlations of the noisy signal to known template signals. Through correlation over these long periods, the signal becomes detectable, even measurable. When the signal to be detected is made-up of pure tones, things are simpler and spectral analyses can readily be used to extract it.

- **Spectral analysis:** Usually this analysis is done using Fast-Fourier-Transforms (FFTs). In that case the template signals are long sinusoids at different frequencies between 0 and *Fs*/2. Individual power spectra are averaged over the whole analysis interval, providing a single average power spectrum over the whole interval. The longer the base of the FFTs, the more apparent the buried signals can become.

- **Time-Frequency analysis:** This is similar to a spectral analysis, except that in that case the individual power spectra are not averaged over the whole analysis interval. They are either short-term averaged, or not averaged at all, and are presented in sequence, providing a two-dimensional graph with a horizontal time scale and a vertical frequency scale.

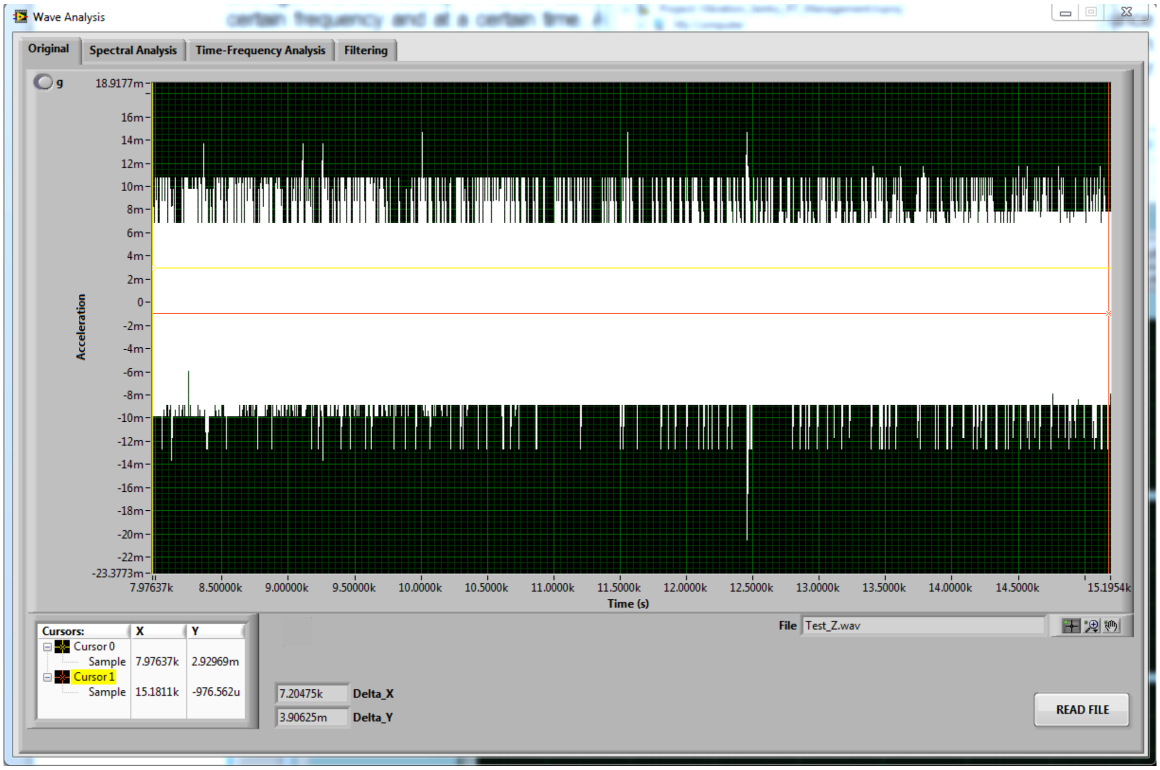
These two tools are part of the *Wave-Analysis* software package.

Note that because these tools rely on the correlation between the noisy signal and the pure sinusoids that form the basis of the FFT, they only work well when the buried signal components are tonal (or at least narrow-band) in nature.

3 Separating the Signal from the Noise

A good procedure to extract a signal buried in noise is to begin by performing a time-frequency analysis. A time-frequency analysis performs a series of FFTs, equally spaced along the signal. Each vertical column in the graph represents the result of an individual FFT in a certain time frame, or the average of a few consecutive FFTs. So each pixel in the graph represents the amplitude of the signal at a certain frequency and at a certain time. A fixed-frequency signal will appear as a horizontal line, since the signal's frequency is the same at all times. A tone of increasing frequency will appear as a line with a rising slope. In that graph the color of the pixel indicates the amplitude of the signal, with stronger signals showing in lighter colors.

Figure 2 shows a time signal sampled at *Fs* = 100 Hz, containing several pure tones. The tones are not detectable in the time signal. The time signal has an amplitude of approximately 10 10^{-3}g, and the quantization is very apparent.



Cursors:	X	Y
Cursor 0		
Sample	7.97637k	2.92969m
Cursor 1		
Sample	15.1811k	-976.562u

File Test_Z.wav

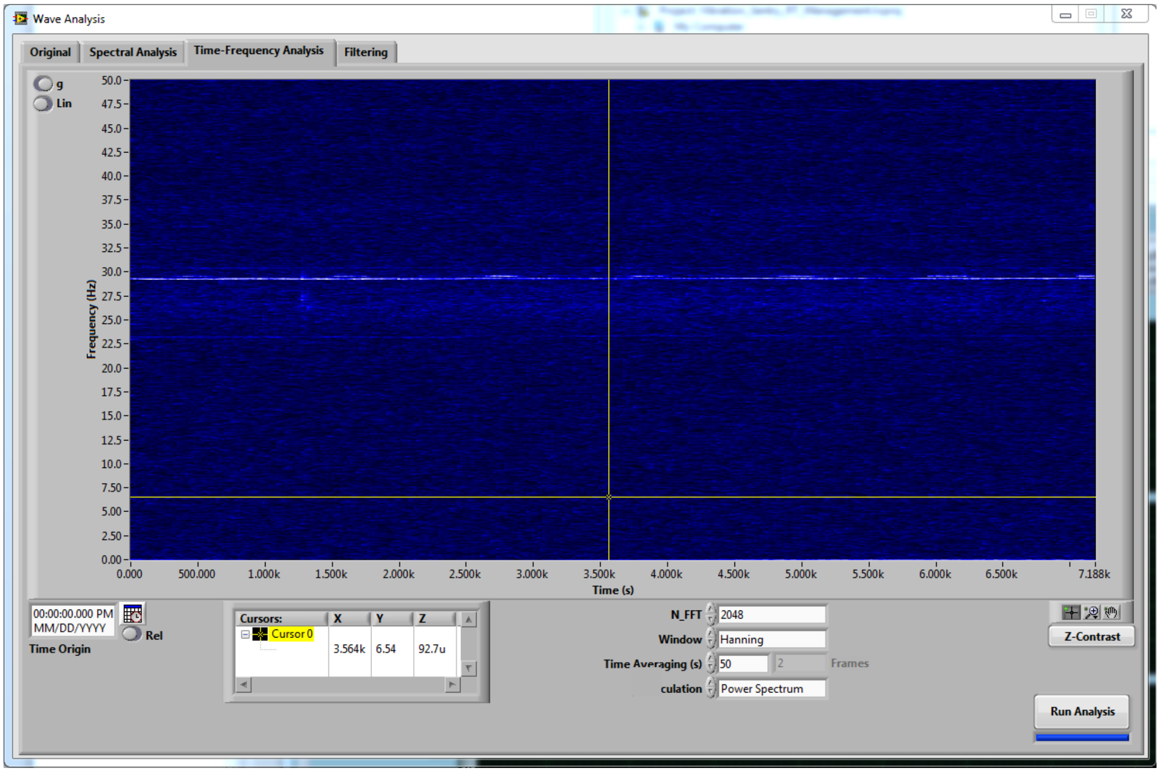
7.20475k Delta_X

3.90625m Delta_Y

Figure 2

Figure 3 shows the corresponding time-frequency analysis. The graph is very "grainy" of course, but it shows the presence of a pure tone of varying amplitude at 29.3 Hz, plus a superimposed "on-off" tone at 29.6 Hz. In addition, a tone of much lower amplitude can be seen at 23.3Hz.

Figure 4 shows a zoom around 29 Hz, showing the main tone at 29.3 Hz, as well as the on-off tone at 29.6 Hz. Note also the slight upward frequency shift of the tone at 29.3 Hz.

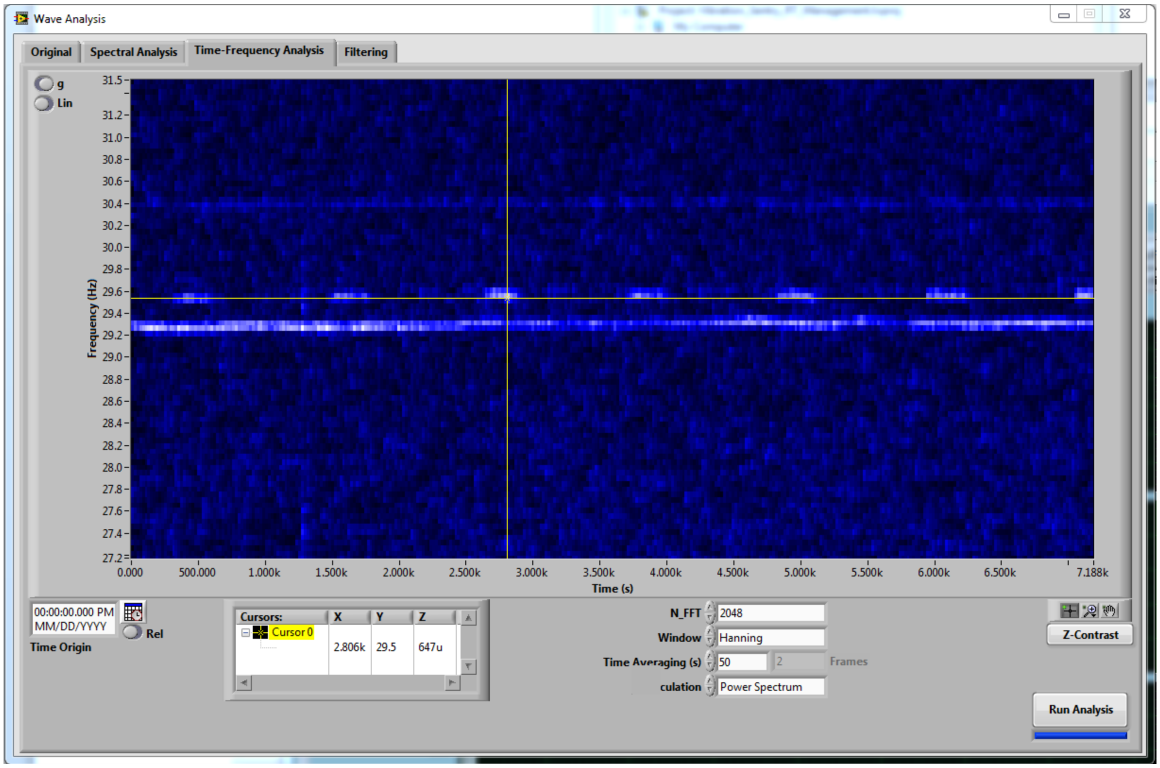


Time Origin: 00:00:00.000 PM MM/DD/YYYY

Cursors:	X	Y	Z
Cursor 0	3.564k	6.54	92.7u

N_FFT: 2048
Window: Hanning
Time Averaging (s): 50 — 2 Frames
culation: Power Spectrum

Figure 3



Time Origin: 00:00:00.000 PM MM/DD/YYYY

Cursors:	X	Y	Z
Cursor 0	2.806k	29.5	647u

N_FFT: 2048
Window: Hanning
Time Averaging (s): 50 — 2 Frames
culation: Power Spectrum

Figure 4

When choosing the FFT size *N_FFT* keep the following trade-off in mind:

- A longer-base FFT (with a larger value for *N_FFT*) will improve the signal to noise ratio for stationary tones, but will make it more difficult to follow fast changes in the tone's amplitude or frequency. Fast changes will blur.

- A shorter-base FFT will track fast changes better, but the frequency resolution will be coarser, each frequency line encompassing a wider bandwidth. Also the signal-to noise ratio for pure tones, and therefore the ability of the analysis to extract weak tones from noise, will be poorer.

4 Measuring the Signal

A cursor can directly be used on the time-frequency graph to measure the amplitude of the tones, as a function of time and frequency. Simply position the cursor on a particular pixel and read the time, frequency and amplitude of the tone at that location. For instance Figure 4 shows an amplitude of 647 μg for the on-off tone. Note that this is an RMS level. If the signal is sinusoidal, its amplitude is 1.41 times the RMS level, or approximately 900 μg.

That is a good factor of 10 below the amplitude of the raw signal!

In the case of a fixed-frequency stationary signal, a spectral analysis also provides a good tool to measure the amplitude of the signal. Figure 5 shows the signal's power spectrum, averaged over the whole length of the signal[1].

Figure 5 shows that the tone at 23.3 Hz has an average amplitude is 196 μg RMS over the interval of interest. Note that this is an RMS level. If the signal is sinusoidal, its amplitude is 1.41 times the RMS level, or approximately 276 μg.

That is a good factor of 40 below the amplitude of the raw signal!

When necessary the cursors in the spectral graph can be used to precisely measure amplitude and frequency.

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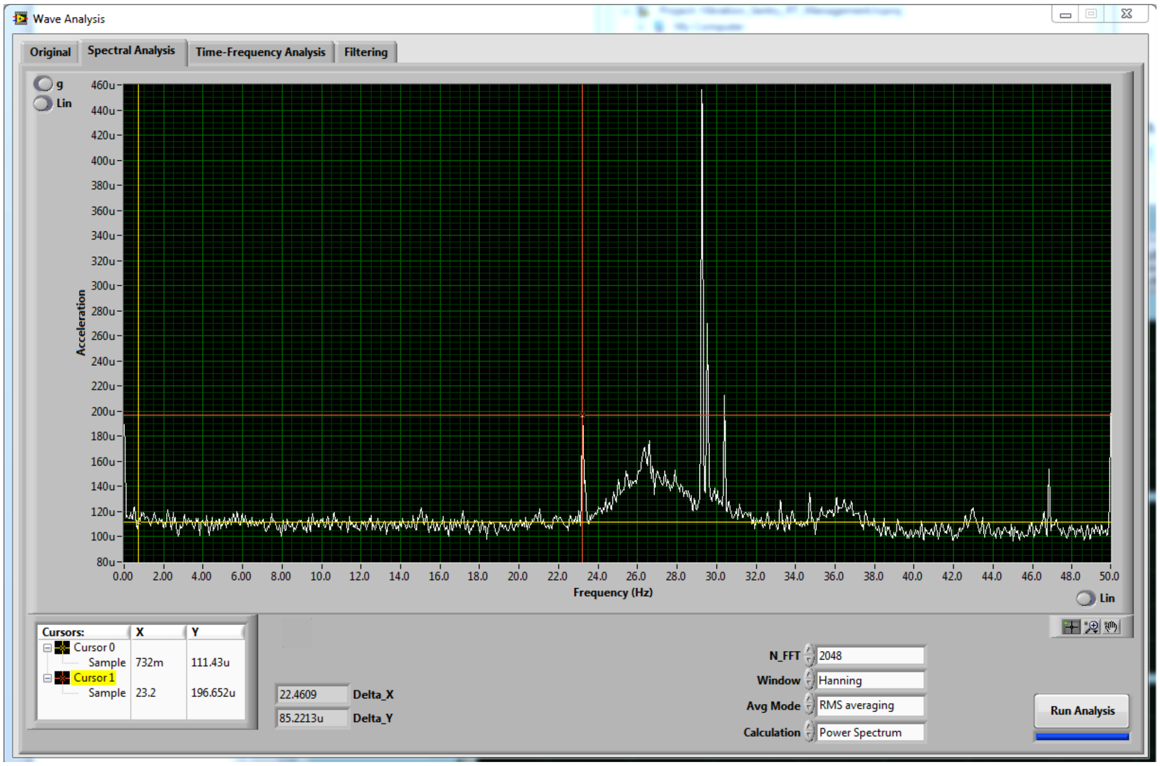
[1] Cursors in the *Original* tab can be used if necessary to limit the analysis to a specific portion of the signal.



Cursors:	X	Y
Cursor 0		
Sample	732m	111.43u
Cursor 1		
Sample	23.2	196.652u

Delta_X 22.4609
Delta_Y 85.2213u

N_FFT 2048
Window Hanning
Avg Mode RMS averaging
Calculation Power Spectrum

Figure 5

5 Conclusion

At 2 mg RMS, the noise floor of the *Vibration Sentry RT* is quite good for an instrument in that price range. Even so, it is easy to detect, extract and measure signals buried more than one order of magnitude below that level. Such detection relies on:

- The buried signals being tonal (or narrow-band) in nature.
- Recording of the raw signal using the *Vibration Sentry RT*.
- Using the *Wave-Analysis* post-processing tools to extract and measure those pure tones from the raw signal.