Sentient ENERGY

# The Importance of Line Sensor Waveform Fidelity


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## Summary

Some years ago, a stereo sound system might be considered a "Hi-Fi" to differentiate it from lesser quality audio equipment. To a true audiophile, the difference means a more enjoyable listening experience. However, in a business setting, high fidelity is a strict requirement for radio stations, movie theaters, and the like.

Likewise, the faithfulness of a signal to its original source is paramount in other areas, such as utility line monitoring. Measurement fidelity assures the ability to:

- Capture the true "peak" of any wave
- Properly sense higher frequency events, such as harmonics and line disturbances

## Sampling Rate

A sensor's internal sampling system will periodically take a "snapshot" of the waveform. Faster sampling rate will always result in a higher fidelity representation of the original wave. However, this comes at the expense of increased costs and processing power, so the practical question for a designer is always how to balance these two factors.

Figure 1 shows one 60 Hz sine wave, sampled at 16 samples per line cycle. Notice that there are no interconnecting lines, only 16 discrete snapshots. These are the only "guaranteed" accurate measurements. Data between the samples can be inferred, but never guaranteed. Clearly, one obvious concern is that some things might be missed. Once missed, this data can never be reconstructed. Only by taking additional samples, can the gaps be filled in with accurate data.

Figure 2 is the same 60 Hz sine wave with 130 sample points. Again, there are no interconnecting lines. The increased number of samples provides additional accurate measurement points. The Sentient MM3 samples at this rate.

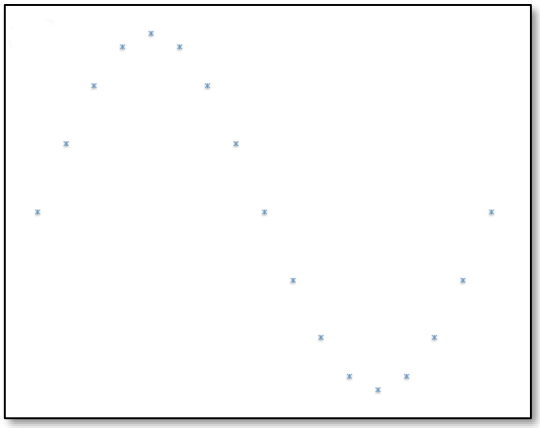


**Figure 1**

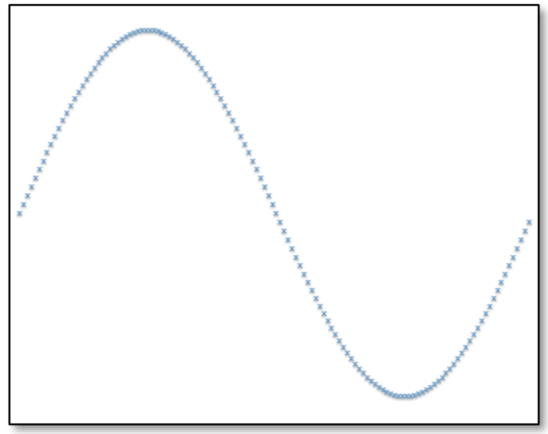


**Figure 2**

Regardless of the sample rate, sensors will perform mathematics on these sample points in order to produce the various outputs of the sensor. Analysis of peak currents, harmonic content, vegetation or equipment disturbances, all use as a basis the discrete sample points as shown above. For display purposes, it is often convenient to draw lines between the data points, to create a graph. This is known as interpolation.

**Interpolation**

The simplest method of interpolation is to use straight lines between sample points, (assuming the wave moves linearity between the points). Although simple, this method is not accurate on sine waves such as these. Given that an engineer knows what a sine wave should look like, we can easily "curve fit" a sine wave into the data points. Using such a process, even a few sample points can be displayed as a very nice looking sine wave. But again, the curves are only an assumption of what really happened during the unknown period between samples.

While, drawing curves between sample points produces a visually appealing picture, some vendors may use the interpolated data to create additional "pseudo-sample" points and thus claim a higher sample rate than the native system actually produces. As noted above, no amount of interpolation can ever create "real" data where none exists.

**Bit Depth**

If we consider that sampling rate is the "horizontal" scaling of the waveforms, (e.g., the time base), then bit depth is the vertical scaling.

A high-fidelity representation of the original signal would require sufficient bit depth so that the system will measure both the greatest amplitude (e.g., 10,000 amps during a fault) and yet still be able to resolve small values (say below 1 amp). In this example, the dynamic range can be expressed as greater than 10,000:1

The Sentient MM3 is unique in the industry by using a true power quality measurement chip to digitize its signals. This chip is designed specifically for utility power applications and is tailored for low error, high resolution, and fast response. The bit depth of this chip produces more than 10 million unique values of numbers. While this may seem like a lot, it creates a very faithful representation of the signal and is a requirement for a high fidelity, high dynamic range line sensor.

Competing devices may use a less expensive ADC, (analog to digital converter) to perform this function. Typically, these parts may have a bit depth of only a few thousand unique values. Again, these values must be spread among measurements from the highest possible level, down to the lower limit of resolution.

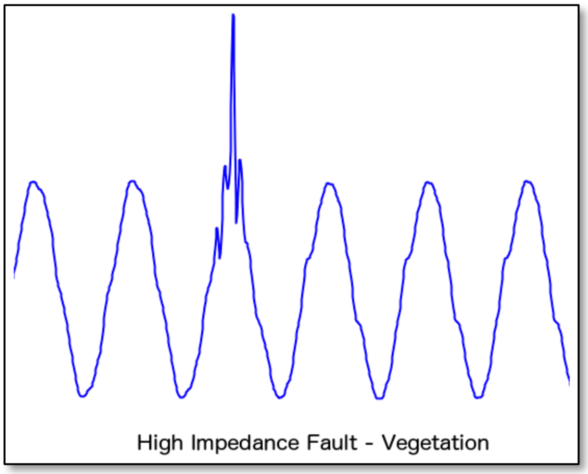
**Frequency Response**

Sample rate is also important, in that it determines the ultimate upper limit of the frequency response. In order to reproduce any analog waveform, it must be sampled at more than twice the highest frequency of interest (the Nyquist rate). The Sentient MM3 sample rate of 130 samples per line cycle equates to 7800 samples per second. Nyquist theorem would therefore state that we can detect frequencies up to 7800/2, or 3900 Hz. This theoretical limit was chosen purposefully to be beyond the frequency range of our power quality chip's upper limit of 1200 Hz. Thus, we can unequivocally record measurements to 1200 Hz (the $20^{th}$ harmonic).

Competing devices are bound by the same Nyquist rate, so a unit that samples at 16 samples per line cycle (960 samples per second), can never possibly digitize any frequency greater than 960/2, or 480 Hz. This is the $8^{th}$ harmonic. So, such a unit is totally unaware of the $9^{th}$ harmonic (an important triplen harmonic).

**Practical Application**

The utility power grid is far from a static, always 60 Hz, system. Line sensors are able to find and detect a myriad of disturbance events. Following are some real-world events captured with an MM3.



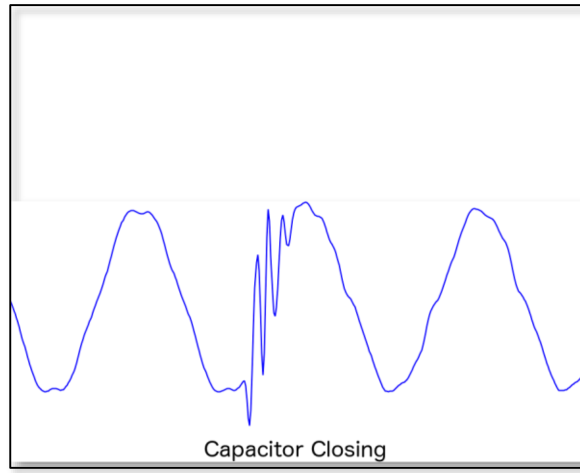




**Figure 3**

**Figure 4**

The MM3 is able to properly measure the value of the peak current of Figure 3. The high sampling rate equates to a narrow observation window. Devices with lower sampling rates might miss this event altogether. Worse yet, by interpolating a sine wave between their data samples, they would grossly misrepresent this event.

The capacitor closing of Figure 4, although a normal event, does demonstrate the superior frequency response of the MM3. The ringing impulse is approximately 750 Hz. Capturing this event requires a sample rate of at least 1500 samples per second (plus similar response rates throughout the device).

**Conclusion** A line sensor's front-end sampling system must capture analog signals and digitize them. The best post-processing can never make up for poor fidelity in the initial digitizing stage. Fast sample rates and high bit depth will assure a system that can find and detect a wide range of events, from high current faults, to low current disturbances. Fast, high frequency events can be a of precursor failing insulators or splices. Often, vegetation contact can be seen before it creates a high current arcing fault. A fast sampling rate allows harmonics to be measured and quantified. Low fidelity sensors simply cannot report, what they don't know. Only a high fidelity sensor can accurately represent its data as being faithful to the original input.

**Questions – Ask your Vendor**

Q. What is your native sample rate, before any interpolation?

*Sentient's MM3 native sampling rate is 130 samples per line cycle*

Q. What is the bit depth of your digitizing?

*Sentient's MM3 is better than one part in 10 million*

Q. What is the upper limit of your frequency response?

*Sentient's MM3 will measure up to the 20th harmonic or 1200 Hz*

Q. Can you provide data showing your performance with high-impedance faults such as vegetation contact?

*Sentient can*