Visualization effects while reconstructing time waveforms from sampled data

TEC/NOT/081

This technical note describes the most common visual effects due to sampling in the time domain. This technical note should be read in conjunction with *TEC/NOT/019 - An Introduction to digital filtering.*

This paper discusses the following topics:

51.1 Overview

In signal processing, sampling is the reduction of a continuous signal to a discrete signal. A common example is the conversion of a sound wave (a continuous signal) to a sequence of samples (a discrete time signal).

A sample is a value or set of values at a point in time and/or space. A sampler is a subsystem or operation that extracts samples from a continuous signal.
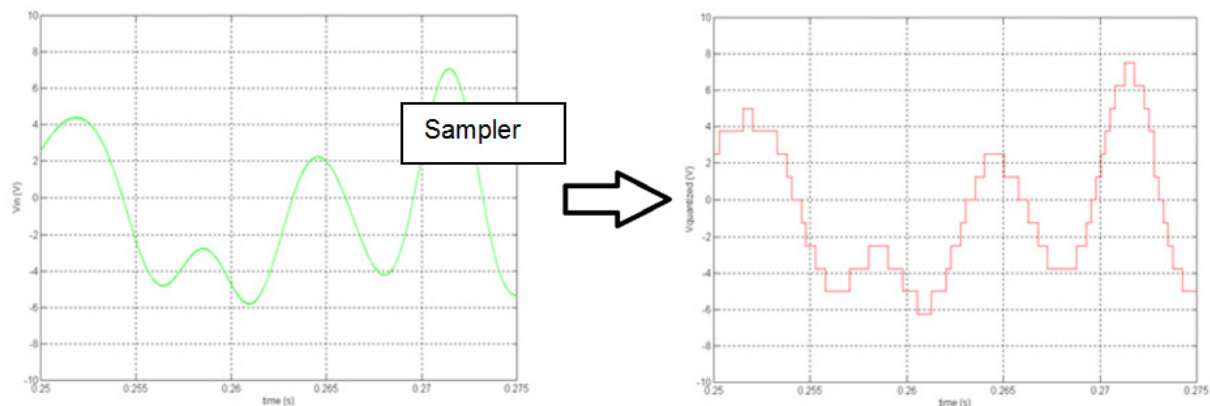

Figure 51-1: Sampler example using rectangular interpolation (see "51.5 Sampling: signal reconstruction" on page 6)

A theoretical ideal sampler produces samples equivalent to the instantaneous value of the continuous signal at the desired points.

NOTE: Aliasing and quantization noise effects are not mentioned in this technical note. They are already discussed in *TEC/NOT/019 - An Introduction to digital filtering.*

51.2 Sampling: amplitude visual effect

When sampled at 100 samples per second, a 0.2Hz sine wave (500 points per period) creates a visually identical shape to the input signal (as shown in the following figure).
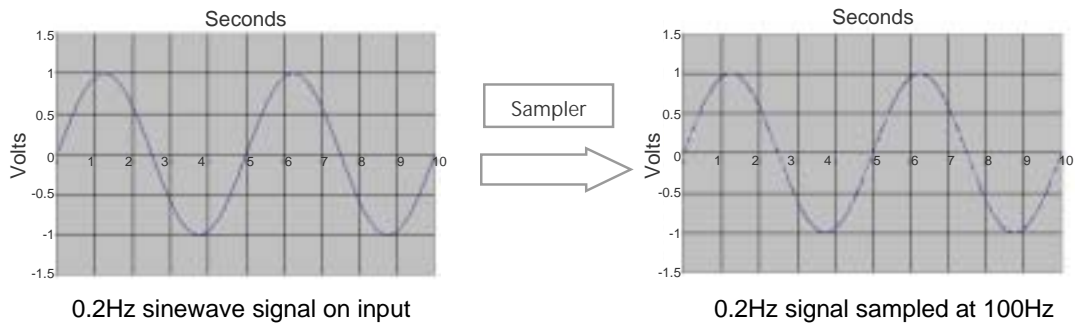

Figure 51-2: Sampler at 100Hz

However, when the same sine wave is sampled at 1 sample per second (5 points per period), the visual aspect of the samples are different. The maximum-minimum is no longer equal to the amplitude (as shown in the following figure).
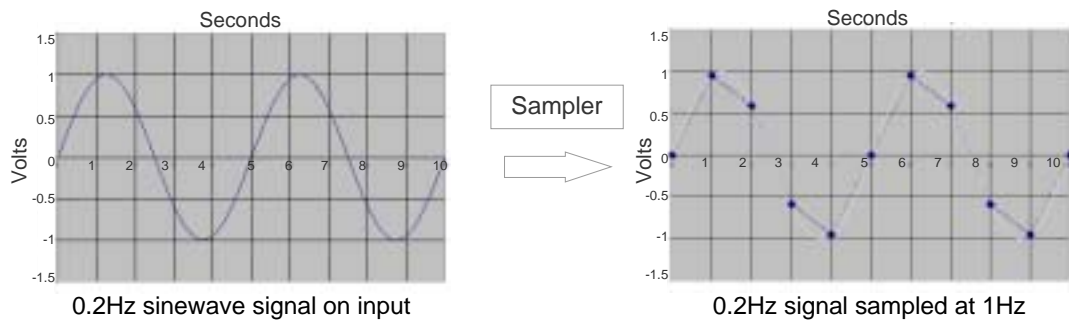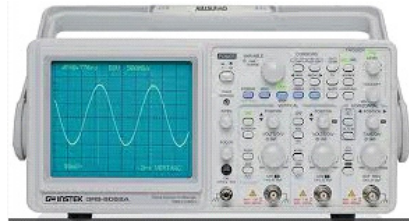

Figure 51-3: Sampler at 1Hz

In the following figure, we want to check the cut-off frequency (F_c) of an analog module. In the example, we input a sine wave at the same frequency (F_{in}) than F_c and expect to see a stable attenuation due to the filter used on the ADC module.
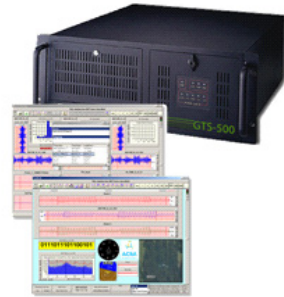
Signal generator
256Hz sinewave signal on input

Oscilloscope
256Hz sinewave signal monitored

KAM-500

Acra KAM-500 ADC module

Sampling result monitored
through GS Works 8

Figure 51-4: Setup for $F_{in} = F_c$

The results that can be seen in GS Works 8 are shown in the following figure.

Signal "attenuation"

ADC module

256Hz sinewave signal on input

256Hz signal sampled at 1024Hz with
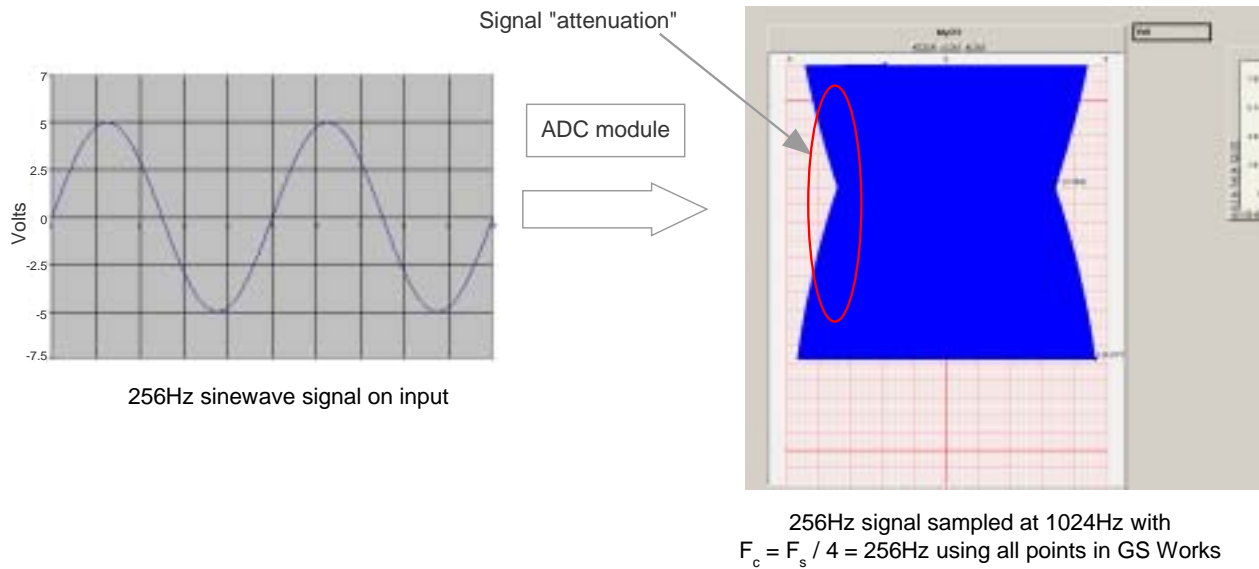$F_c = F_s / 4 = 256Hz$ using all points in GS Works

Figure 51-5: Sample result for $F_{in} = F_c$ using GS Works showing attenuation

As seen in the GS Works 8 screen, the attenuation is not stable. However, this is a visual effect caused by F_{in} not being in perfect synchronization with F_s. The signal generator/Acra KAM-500 clock varies slightly causing the maximum-minimum to vary, which explains this visual aspect.

NOTE: If $F_{in} \times 4$ is slightly off F_s, the sample points shift, and peak-peak voltage goes slowly down, and then up again. At $F_{in} \sim 0.5F_s$, you may see a DC signal response (when the samples are exactly at mid-point of your input sine wave amplitude).

Running an FFT on the resulting signal that's been sampled provides the correct amplitude with no attenuations seen.

51.3 Sampling: square wave visual effect

In theory, a square wave contains an infinite component of odd-integer harmonic frequencies.

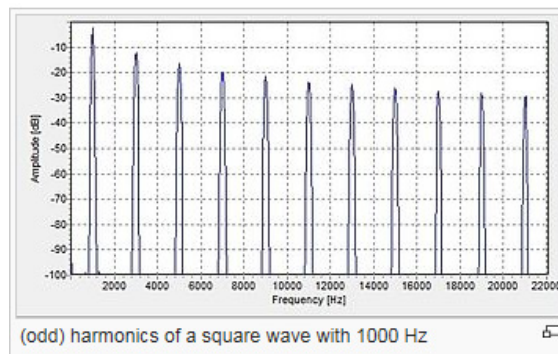(odd) harmonics of a square wave with 1000 Hz

Figure 51-6: Harmonics of a square wave

As shown in the following figure, sampling a square wave does not display a square wave visually; filtering is not performed before the sampling.
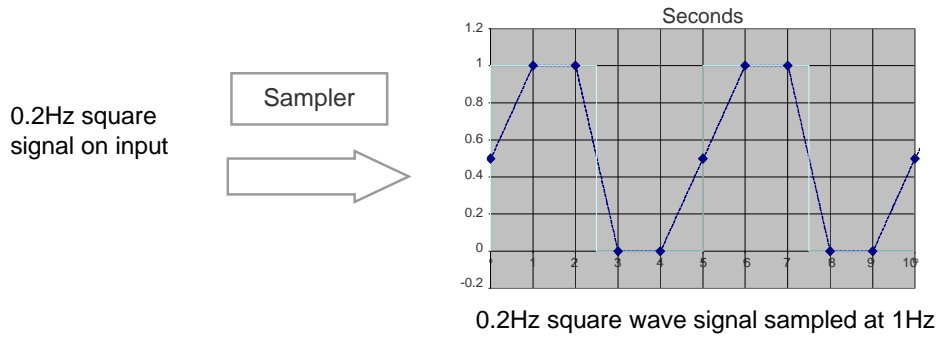
Seconds

0.2Hz square
signal on input

Sampler

0.2Hz square wave signal sampled at 1Hz

Figure 51-7: Sampling a square wave and displaying results with linear interpolation between points

Because a square wave has infinite harmonics, and the Acra KAM-500 ADC module filters out the harmonic frequencies above F_C, the sampled result exhibits some overshoot/undershoot ringing effect (due to absence of the filtered harmonics) as shown in the following figure.

50Hz square
signal on input

ADC

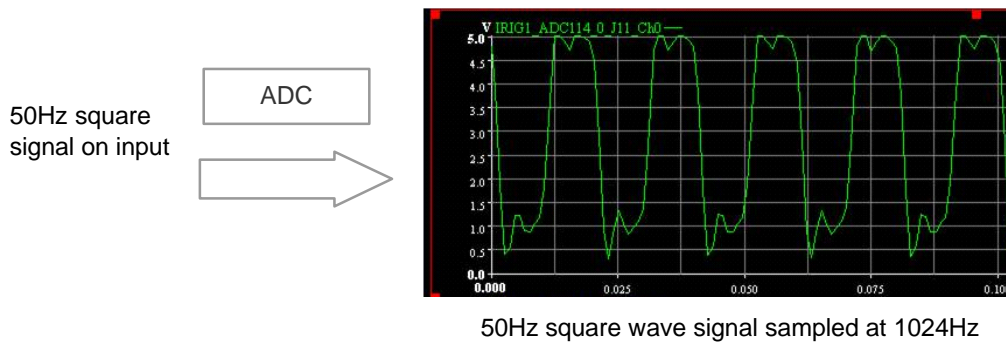50Hz square wave signal sampled at 1024Hz

Figure 51-8: Sampling a square wave using a KAM-500 ADC module

If a period/frequency/pulse width measurement was the goal of sampling a square wave, an Acra discrete input (DSI) type module is more appropriate. Otherwise, it is recommended to sample the ADC module as fast as possible using the highest F_c setting such as $F_c = 16F_s$. This type of setting attenuates the ringing affect further but may introduce unwanted affects such as aliasing.

51.4 Sampling: screen effect

When viewing plots containing a large number of sample points, the true nature of the waveform could be hidden, due to visual effects (Moiré effect) caused by the closely spaced lines. Re-scaling the plot to reduce the number of viewed sample points, reduces this visual effect and the true waveform becomes more apparent.

The following figures show how the Moiré effect can hide the true waveform being viewed.
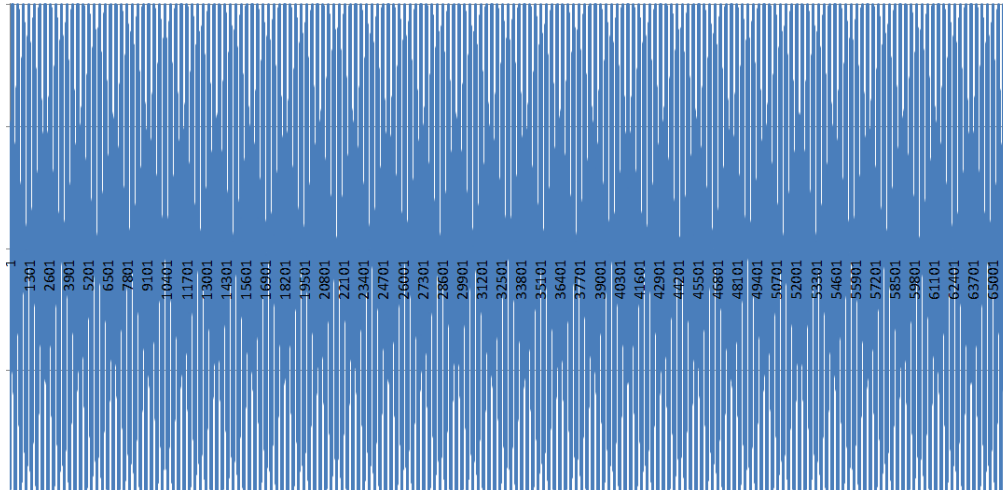

Figure 51-9: Sine waves plotted in Excel – 65536 points and 360 periods

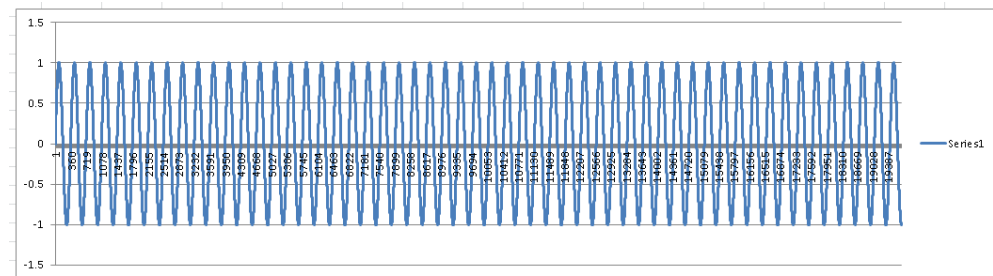The same sine wave rescaled to have less points shows the expected signal.

Figure 51-10: Sine waves plotted in Excel – 20000 points

In GS Works 8, this would be equivalent to clicking the resolution buttons mm/sec.

Figure 51-11: GS Works 8 resolution buttons

51.5 Sampling: signal reconstruction

The following figure shows two methods for reconstruction of an original signal (green line):

Rectangular - which extends the sample value across ± 0.5 of the time sample (pink line)

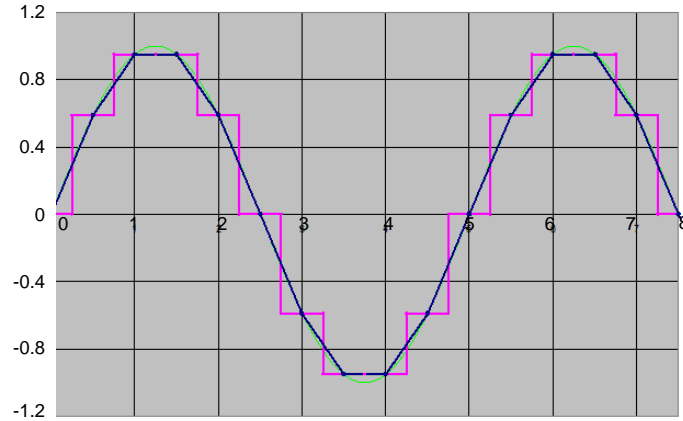Linear - which joins each sample with a straight line (blue line)

Figure 51-12: Simple signal reconstruction

These are simple methods that require almost no post-processing and they work well with any periodical and non-periodical signals.

The disadvantage is that they require a much higher sample rate than the maximum frequency of interest to visualize the original signal. For a linear reconstruction, they require at least 10 times higher F_s, while for a rectangular reconstruction at least 30 times higher F_s is required.

NOTE: GS Works 8 has an option on the strip charts called Digital Draw Style. When enabled, it implements a digitized drawing style (rectangular reconstruction) instead of drawing a smooth curve between data points.
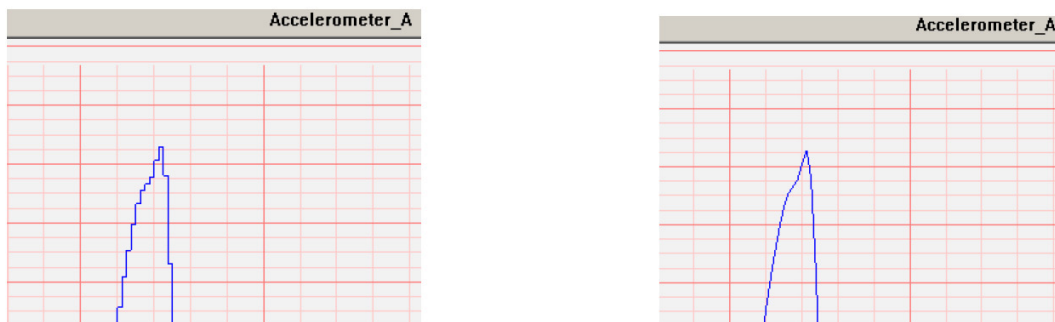
The effect of drawing digital (left) compared to smoothed drawing (right)

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