

Interactive Simulation with a LabVIEW Virtual Instrument Including Magnitude Change, Phase Shift and Aliasing:

"What we get is not what it is - Part II!"

<http://www.kostic.niu.edu/sampling.htm>

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Category: Academic

Products Used: LabVIEW®

The Challenge:

Develop a virtual instrument for interactive, what-if simulation of sampling of arbitrary periodic signals, and demonstrate influence of different instrument properties on the sampled/measured signals, including damping, sampling and natural frequencies.

The Solution:

An interactive LabVIEW virtual instrument is developed to qualitatively and quantitatively simulate sampling of an arbitrary frequency signal while changing instrument settings. The effects of damping, natural frequency, phase lag, magnitude, and sampling frequency on the measured signal is observed graphically and interactively.

Abstract:

In addition to real measurements, the LabVIEW is very effective application for interactive what-if simulation in education. A previously developed virtual instrument is further enhanced to simulate measurements while arbitrary changing instrument properties, including the damping, phase shift, magnitude ratio, and natural and sampling frequencies. The effect of virtual instrument properties on any measured signal is observed interactively, both qualitatively (graphically) and quantitatively (numerically). Sampled signal distortion, including the magnitude change, time or phase lag, as well as peculiar interference phenomena, like "beat" wave, aliasing, and others, are effectively demonstrated. The virtual instrument may be set for interactive use over the Internet. Users may interactively change the signal and virtual instrument characteristics and witness first hand that *"what we get is not what it is!"*

Introduction

Learning is a challenging intellectual process, and new technologies have tremendous potential to make an immense difference with its interactive (computational) and multimedia features. When a user/learner is in "the driver seat," the virtual-reality, if well designed, may have many advantages over the reality itself – remember, *"I hear...and I forget, I see...and I remember, BUT, I do...and I understand!"* That is why kids love video games, like TV, but hate old-fashioned lectures. For many, since we are in the beginning of the information revolution, it is hard to comprehend that interactive/computational simulations will make another revolution in the 21st century in many areas, the way steam power or electricity made industrial revolution in previous centuries. The LabVIEW has an advantage to further enhance the simulation applications due to its powerful features and an appealing, real-like "front panel" interface.

This paper expands on similar paper by accounting for influence of instrument natural frequency and damping on the magnitude ratio and phase shift of the measured signal, in addition to the sampling frequency influence on aliasing [1]. Here, an interactive virtual instrument is developed to simulate the second-order (measurement) system, a basic concept in many science and engineering courses, like physics, dynamics, control, and measurement methods [2]. While students learn procedures to calculate the system frequency response (magnitude ratio and phase shift) as function of damping and frequency ratios, many do not fully comprehend how these do influence/modify the real-time signal output. As the aliasing phenomena are added to the measurement challenge, the students become confused and discouraged to get involved and interested to fully understand these important physical processes. The

developed LabVIEW virtual instrument allows users to experiment (or play) with different (arbitrary) signals and instrument characteristics and interactively (immediately) see the relevant outcomes, both qualitatively (visually/graphically) and quantitatively (numerically). This interactive module will stimulate users' curiosity and motivate them to conveniently "check out" different options and possibilities, and thus accelerate experience and by active inquiry and "experimentations" enhance their comprehension and interest for deeper thinking and understanding. These new learning tools are not and cannot replace the traditional learning by cognitive thinking, but, if designed well, the new simulation tools may qualitatively enhance learning environment by stimulating inquiry and building confidence and motivation.

Virtual Instrument and Results

To interactively sample or measure (evaluate and plot) a signal $[y(t)=A\sin(2\pi ft)]$ versus sampling time (t), the appropriate simulation procedure is developed as a LabVIEW virtual instrument, to sample or measure a "real" signal (y) of frequency (f) with any sampling frequency (f_s), instrument natural frequency (f_n) and damping ratio (z), or alternatively with the given sampling-to-signal frequency ratio ($R_{fs}=f_s/f$), given magnitude, i.e. measured or sampled-to-signal (output-to-input) amplitude ratio ($M=A_M/A$, thus $A_M=AM$, $A_M=M$ if $A=1$ for convenience) and phase shift or phase lag $\mathbf{f}(phi)$. Based on the input signal and instrument characteristics, the virtual instrument interactively evaluates the corresponding output, $y_M(t)=y_a(t)=A_M\sin(2\pi f_a t - \mathbf{f})$, and presents it graphically and numerically, along with other characteristic results, like sampled (or measured, f_M , or aliasing, $f_a=f_M$) frequency, phase shift (or phase lag) \mathbf{f} , magnitude ratio M , or similar. The characteristic "measured" quantities are evaluated using the following relations:

$$(Eq.1): f_M = f_a = \begin{cases} f, & \text{if } 0 \leq f \leq f_{Nyq} \\ 0 \leq f - n_{\max} f_{Nyq} \leq f_{Nyq}, & n_{\max} = \text{maximum even positive integer} \\ 0 \leq (n_{\min} + 1) f_{Nyq} - f \leq f_{Nyq}, & n_{\min} = \text{minimum odd positive integer} \end{cases}$$

$$(Eq.2): \mathbf{f} = \tan^{-1} \frac{2z \frac{f}{f_n}}{1 - \left(\frac{f}{f_n}\right)^2}; \quad \text{where } 0 \leq \mathbf{f} \leq \mathbf{p}[\text{rad}]$$

$$(Eq.3): M = \frac{A_M}{A} = \frac{1}{\sqrt{\left[1 - \left(\frac{f}{f_n}\right)^2\right]^2 + \left(2z \frac{f}{f_n}\right)^2}}$$

where, $f_{Nyq}=0.5f_s$ and f_n are the Nyquist and instrument natural frequencies, respectively.

As seen in Figure 1, the input variables are presented as the virtual instruments controls on its control panel. Starting from the top to the right, there are: signal frequency (f) control knob; sampling frequency (f_s) control knob, below which are natural frequency (f_n) and damping ratio (z) control knobs. Next are interactive ON/OFF switch and "Choose-MODE" flip-switch. If the interactive switch is ON, the sampling is in a continuous measurement or interactive mode, otherwise it is in a single mode. The Choose-MODE switch, if flipped to the right, activates the three knobs to the right of it, namely, sampling-to-signal frequency ratio, magnitude ratio and phase lag, respectively. Depending on the Choose-MODE switch position, either knobs to the right or to the left of it are active at a time, while the other settings, if conflicting, are ignored. The output (sampled or measured) quantities are displayed on the three graphs along with the characteristic numerical values as labeled on the front panel.

Several characteristic examples are presented on Figures 1, 2, and 3 and will be discussed in the following section. As seen on these Figures, the same signal "measured" with different damping ratios and natural and sampling frequencies, appears quite differently in form, shape, and even frequency. This paper's theme phrase, "What we see is not what it is!" is compellingly self-evident. Using the developed virtual instrument one may interactively (very clearly and vividly) experiment with different input values, and qualitatively and quantitatively demonstrate influence of instrument characteristics, like sampling and natural frequencies and damping, on measurement of periodic signals. Note that the frequency ratio (R_{fs}) is equal to the number of sampled points per signal's period or cycle!

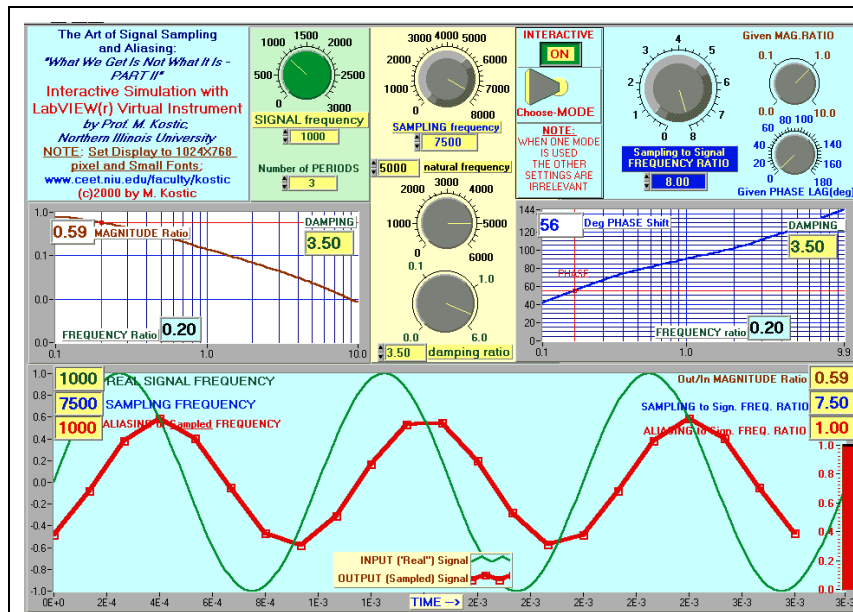


Figure 1: Front Panel Interface:

“Choose-MODE”: Left-flip

“Input”:

Signal frequency: 1000 Hz
 Number of periods: 3
 Sampling frequency: 7500 Hz
 Natural frequency: 5000 Hz
 Damping ratio: 3.5

“Measured Output”:

Frequency ratio: 0.20
 Magnitude ratio: 0.59
 Phase lag (shift): 56 deg
 Measured (aliasing) frequency: 1000 Hz
 Sampling-to-signal frequency ratio: 7.50
 Aliasing-to-signal frequency ratio: 1.00

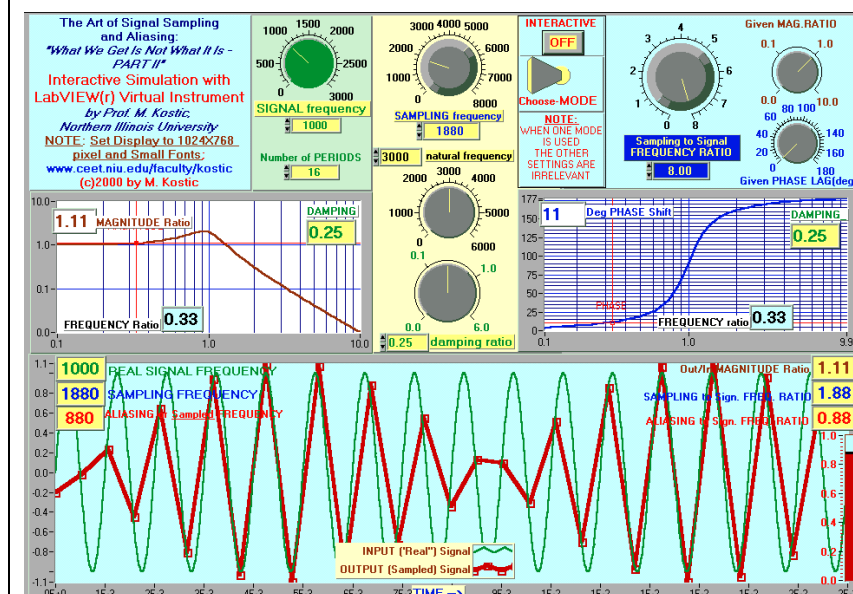


Figure 2: Front Panel Interface:

“Choose-MODE”: Left-flip

“Input”:

Signal frequency: 1000 Hz
 Number of periods: 16
 Sampling frequency: 1880 Hz
 Natural frequency: 3000 Hz
 Damping ratio: 0.25

“Measured Output”:

Frequency ratio: 0.33
 Magnitude ratio: 1.11
 Phase lag (shift): 11 deg
 Measured (aliasing) frequency: 880 Hz
 Sampling-to-signal frequency ratio: 1.88
 (close to 2, “Beat-wave”)
 Aliasing-to-signal frequency ratio: 0.88

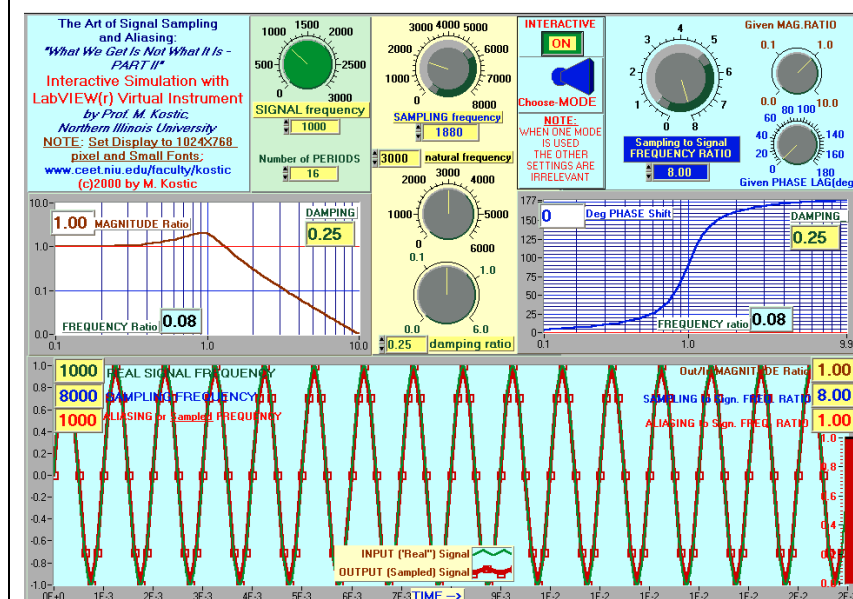


Figure 3: Front Panel Interface:

“Choose-MODE”: Right-flip

“Input”:

Signal frequency: 1000 Hz
 Number of periods: 16
 Sampling-to-signal frequency ratio: 8.00
 Given Magnitude ratio: 1.00
 Given Phase Lag: 0 deg

“Measured Output”:

Frequency ratio: 0.08
 Magnitude ratio: 1.00
 Phase lag (shift): 0 deg
 Measured (aliasing) frequency: 1000 Hz
 Sampling frequency: 8000 Hz
 Aliasing-to-signal frequency ratio: 1.00

Discussion and Conclusion

It is evident in Figure 1 that the output (i.e. measured or sampled) signal does not represent the exact image of the input signal, which is always the case to a smaller or a larger degree. For the signal of 1000 Hz, for example, the sampling frequency of 7500 Hz (7.5 ratio) is good enough to avoid aliasing and get a good shape of the signal. However, the instrument natural frequency of 5000 Hz and 3.5 damping ratio are not good enough, thus attenuating signal magnitude to 59% of its original value (0.59 the magnitude ratio) and resulting in a phase lag of 56 degrees. In Figure 2 the undersampling with 1880 Hz, results in aliasing with measured (or aliasing) frequency of 880 Hz, and with a peculiar, so called "beat-wave" shape of frequency of 120 Hz, since the sampling-to-signal frequency ratio of 1.88 is smaller than 2 (thus aliasing), but close to 2 (thus "beat-wave" phenomena), the critical Nyquist value of 2. The aliasing phenomena are explained elsewhere [1], as well as related online experimentation is made available over the Internet [3]. Also, the small damping and signal-to-natural frequency ratios (0.25 and 0.33 respectively) result in a small resonance ($1.11 > 1$ magnitude ratio) and a phase lag of 11 degrees. Finally, in Figure 3, a good representation of the input signal is achieved by selecting the sampling-to-signal frequency ratio of 8 (no aliasing, good shape), magnitude ratio of 1 and phase shift or lag of 0 (this time using the "right-flip" Choose-MODE).

As already stated in the Introduction, the developed LabVIEW virtual instrument allows users to experiment (or play) with different signals and instrument characteristics, and interactively see the relevant outcomes, the system/instrument frequency response and aliasing if present, along with input ("real") and output ("measured or sampled") signals, both qualitatively (visually/graphically) and quantitatively (numerically). This interactive module will stimulate users' curiosity and motivate them to conveniently "check out" different options and possibilities, and thus accelerate experience and by active, what-if inquiry and "experimentations" enhance their comprehension and interest for deeper thinking and understanding. These new learning tools are not and cannot replace the traditional learning by cognitive thinking, but, if designed well, the new simulation tools may qualitatively enhance learning environment by stimulating inquiry and building confidence and motivation – in short, may become a "virtual eye and mind opener"!

References:

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2. Figliola, R.S., and D.E. Beasley, *Theory and Design for Mechanical Measurements* - 2nd Edition, Wiley, 1995.
3. Kostic, M., *"The Art of Signal Sampling and Aliasing -- An On-Line Experiment: "What we see is not what it is!"*
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Author Biography:

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