Guidance Notes on Filtering and Sampling

Frequency Response

The information content available in the signal channels of a dynamic testing machine is directly related to the signal bandwidth. The fundamental limitation in most measuring systems is the bandwidth of the transducer itself.

In most testing machines it is the load cell that will be the limiting factor in the form of its mechanical resonance. Most low profile strain gauge load cells will have a natural resonant frequency in the range 4000 Hz to 5000 Hz with an internal effective mass typically in the region of 0.5 kg. When typical external specimen adapters are added we can expect this resonance to fall to about 3 to 3.5 kHz. Strain gauge beam type load cells, suitable for measuring lower load range forces than typical low profile devices, will typically have much lower natural frequencies.

It is generally accepted that, in order to keep measuring errors low, a load cell should not be used at frequencies above about 0.3 of its resonant frequency, hence input filtering is imposed to limit the signal bandwidth accordingly.

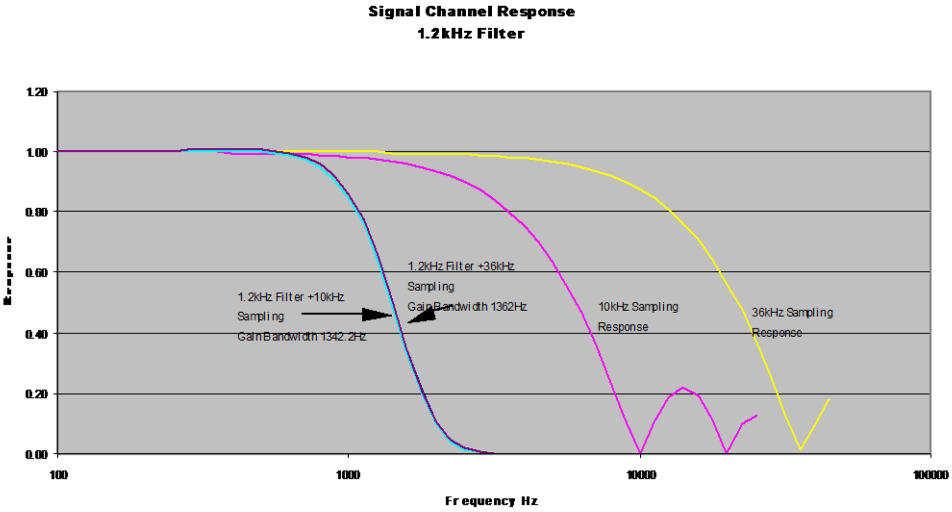
We normally apply some filtering on measuring channels in order to eliminate higher frequency signal noise and aliasing. The same characteristic filter should be used on all channels, especially in high frequency systems, to ensure that the information from different channels can be directly correlated and is not subject to differing time delays.

When sampling the signals processed by a filter it is important to sample at high enough a rate to preserve the information in the original signal. The Nyquist Sampling Theory indicates that the minimum acceptable sampling rate is twice the maximum frequency of interest. The measured amplitudes of signals at half the sampling rate are attenuated to 64% of their true value and it is good practice to sample at higher rates wherever possible.

With a system sampled at 10 kHz, a 1 kHz signal, which would have suffered 36% attenuation with 2 kHz sampling, only suffers 2% attenuation. The graph shows the differences between the combined effects of a 1.2 kHz input filter and the attenuation effects of 10 kHz sampling and 36 kHz sampling. The differences are barely noticeable.

Estimating the gain bandwidth product (an estimate of the information carrying ability of the system) shows that the 36 kHz sampled system is only 1% better than the 10 kHz system. In other words sampling faster than necessary may produce more data but not more information! We could obtain the same amount of data by using a lower sampling rate and simply interpolating between the samples.

To conclude, the Sampling rate of the system should be well matched to its signal bandwidth in order to preserve information content. Furthermore the signal bandwidth should be well matched to typical measuring transducers.

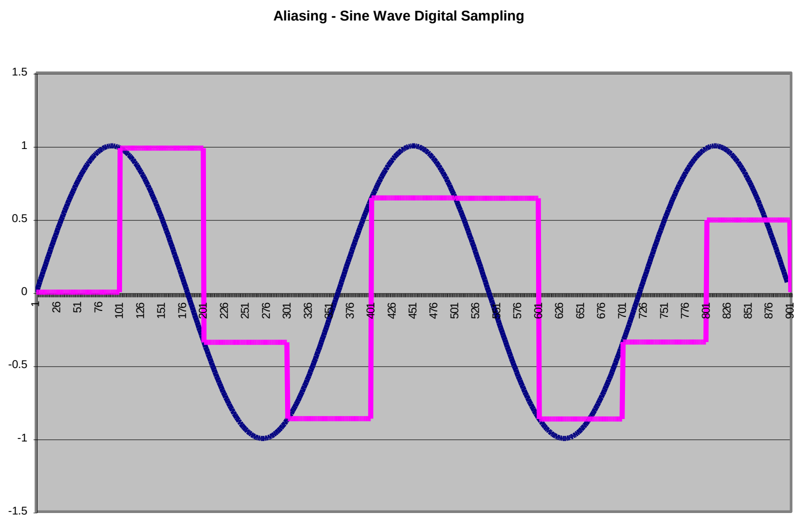


Aliasing

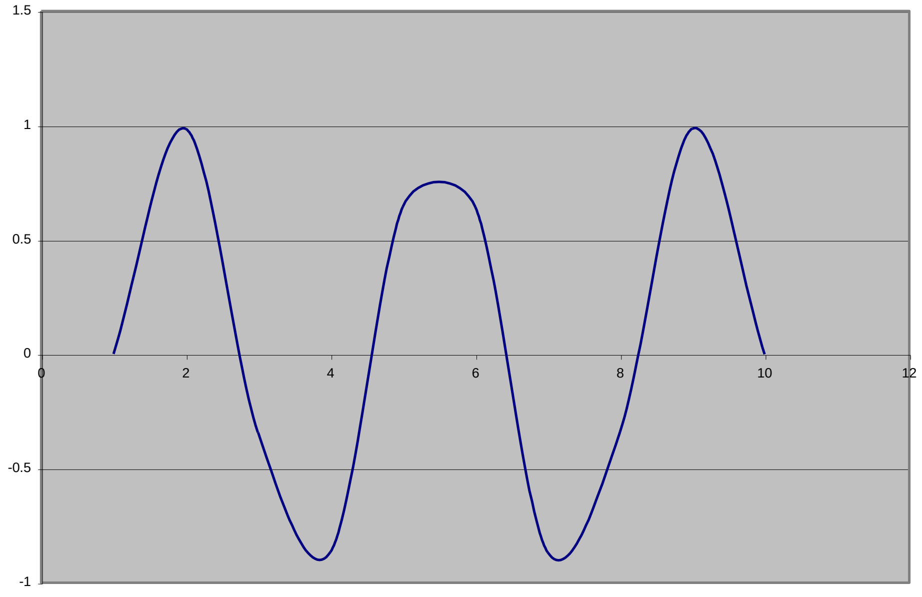
Aliasing occurs when the sampling rate is too low for the frequency response of the system. As a simple example of aliasing, consider sampling the levels of illumination by looking out of the window, at the same time, just once per day. If the observations were always made at midnight, the collected data would imply that it was always dark outside. If the observations were always made at midday, the collected data would imply that it was always light outside.

Now, assuming that there are twelve hours of darkness and twelve hours of light, consider taking three samples per day, at eight hours interval. If sampled at 1200, 2000 and 0400, the observations will indicate twice as much dark as light. If sampled at 0000, 0800 and 1600, the observations will indicate twice as much light as dark.

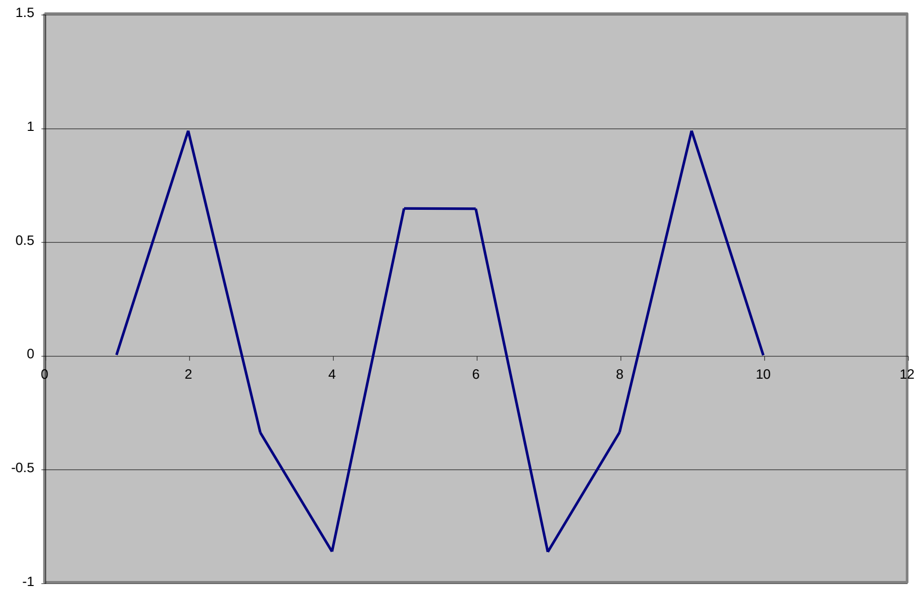
As the signal is varying twice per day (from day to night) the absolute minimum sampling rate in order to avoid aliasing would be four equi-spaced observations per day.



The above graph shows the effect aliasing when sampling a sine wave every 100 degrees, which is equivalent to sampling a 360 Hz signal with a 100 Hz sampling rate.



The above graph shows the 100 degree sampled data plotted with a "curve fitting" graph setting.

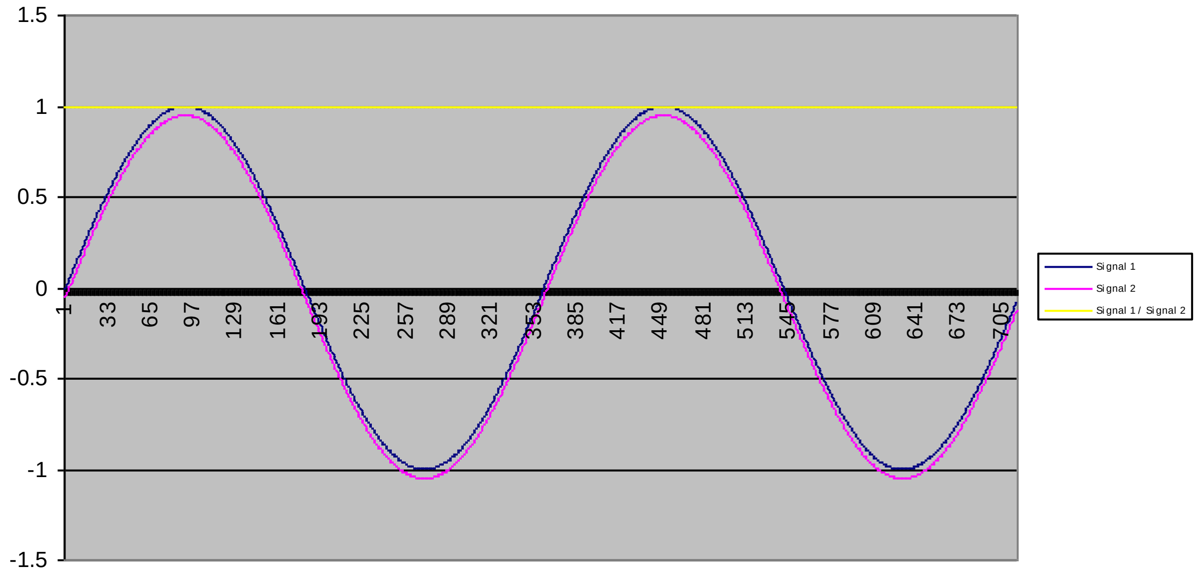


The above graph shows the 100 degree sampled data plotted with a "point-to-point" graph setting.

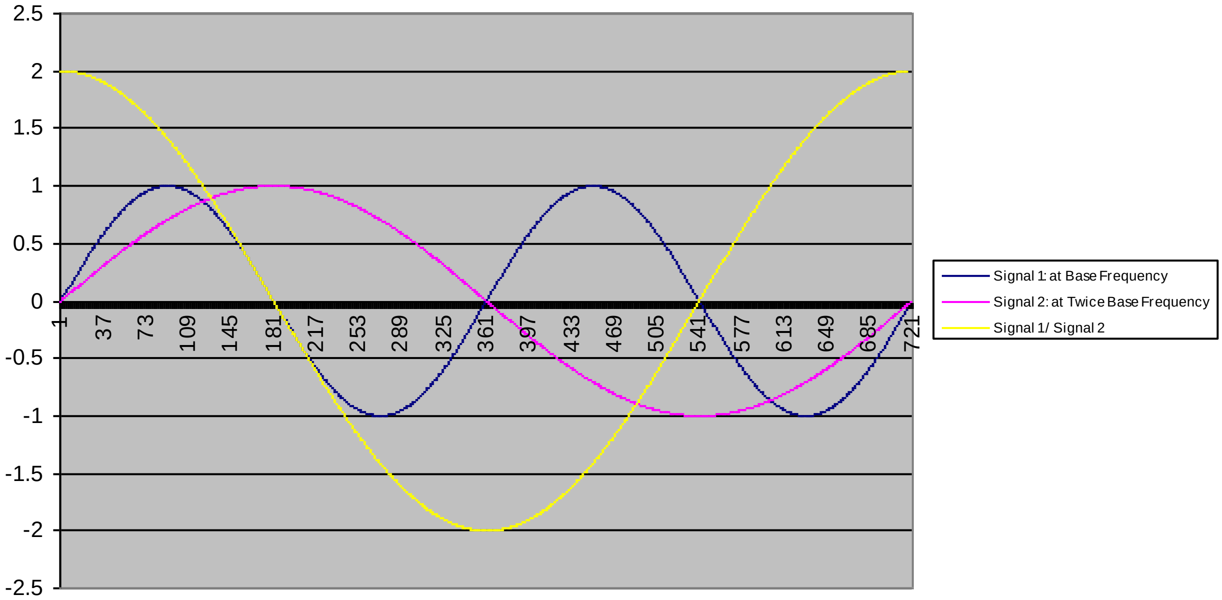
Phase Angle Errors

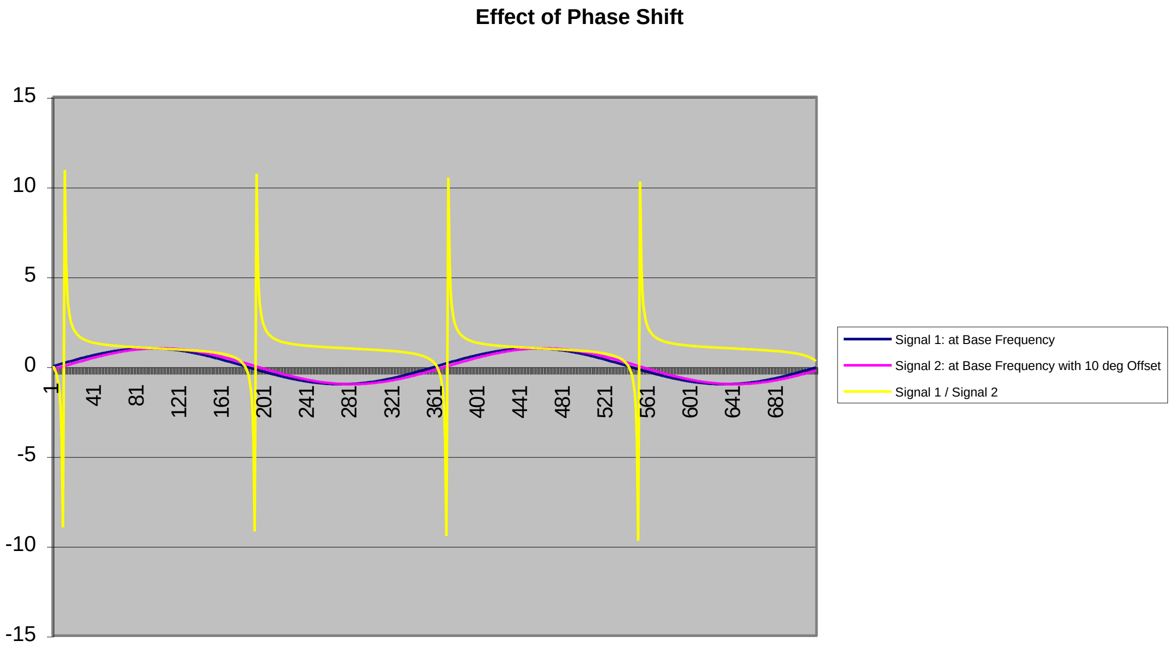
Ignoring the effects of frequency response can lead to some interesting errors, which can, for the uninitiated give rise to some spectacular errors. This is especially the case where one dynamic signal is divided by another, in order to give, for example, a friction coefficient reading. The following provides a graphical illustration of this point:

Equal Frequency Response & Zero Phase Shift



Effect of Frequency Response





Clearly, if presented with a friction coefficient graph of the above form, alarm bells should start ringing.