

DATA ACQUISITION AND THE ALIASING PHENOMENON

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ABSTRACT

In current practice sensor data is digitized and input into computers, displays, and recorders. To try to reduce the volume of digitized data, our original hypothesis was that by selecting a subset of digital values from an over-sampled signal, we could improve signal identification and improve perhaps Nyquist performance. Our investigations did not lead to significant improvements but did clarify our thinking regarding the usage of digitized data.

KEY WORDS

Aliasing, spectral peaks, spectral pairs, sample digitizing rate, and Nyquist frequency

INTRODUCTION

Digital data acquisition of sensor data is an online, real time, non-invasive, point by point measurement activity. Single point by point data values are not sufficient to provide frequency information. Frequency analysis is a mathematical offline software process involving stored blocks of data point values coupled with data rate timing information. The analysis program places requirements on the acquisition data activity for bandwidth and dynamic range issues.

DATA ACQUISITION

Telemetry has been defined as Telemetering or metering at a distance. In practice this means collecting multi-channel analog data from sensors at remote sites such as test stands or from a moving platform such as an aircraft, helicopter, or test missile. The multi-channel data would be transferred from the remote site to a fixed site via wire or optical fiber in the case of the test stand. For the moving platform the data would be transferred via an RF data link to a ground station complex. The actual transmission methodology would be multiplexed pulse code modulation for digitized data or frequency division multiplexed FM subcarriers for analog data.

At the ground station or fixed site, the PCM streams from the remote site or the moving platform are decommutated and fed to the ground station quick look, recording, and computer interfaces. In similar fashion the multiplexed FM subcarrier channels would be demodulated, digitized and fed to similar quick look, recording, and digital interfaces.

Thus the multi-channel analog sensor data from the remote site or the moving platform has been converted to digital input data as separate digital words which are fed to the ground station subsystems and computer. The data is no longer in continuous analog form but rather in gapped, sampled data format. In essence a digitizer converts short time samples of the analog sensor data to digital values of corresponding magnitude. The digitizer can be set to provide single digital values on command, or be clocked at a known digitizing rate. It will be noted that knowing the exact digitizing rate is essential for making frequency determinations for frequency analysis purposes.

SENSOR SIGNAL ISOLATION

To protect the validity of the successive digital samples, the original analog sensor data is often buffered and/or the input impedance of the digitizer is sufficiently high that there is no loading by the digitizer sampling process. The analog sensor data stream is unaffected by the sample digitizing process. There is no effect on the individual time samples of the varying sensor data. The clock rate for the digitizer could be radically changed without affecting the validity of the digitizing process. A separation exists between the sensors analog data progression and the successive digitized samples, thus there can be no effect on either time domain or frequency domain data rate progression. It will be seen that the Nyquist criteria and the aliasing phenomenon are functions of the computer's non-real-time software manipulations rather than inherent in the clocked sample digitizing process.

In general there are three classes of data streams, each dependent on the rate of change of the sensor data for a particular channel relative to its sampled data rate. The lowest data rate material would be data logging of temperatures and voltage measurements, or perhaps mechanical creep data. The next class of data would be for streams of moderate rate of change of data such as time-data-history channels showing general data trends. The third and highest rate of change channels would be those for which spectral analysis would be applied for resonance and vibration frequency determination.

THE NYQUIST CRITERIA

The Nyquist criteria states that the sampling or digitizing rate must be a minimum of 2 or more times the highest frequency of interest in the digitized data stream. The particular value of the highest frequency of interest is referred to as the Nyquist Frequency. In each cycle of the Nyquist Frequency there is a positive half cycle and a negative half cycle. Should the digitizer specific sampling rate fall on the zero and 180 degree points of the Nyquist Frequency, the sampler would report a zero signal. Therefore the sampling rate (SDR) needs to be set to more than two times the Nyquist Frequency value. Typically, sampling rate values range upwards from 2.38 times the Nyquist Frequency. Conversely, the Nyquist Frequency will automatically be less than $\frac{1}{2}$ the SDR sampling rate.

Our original hypothesis was that by selecting particular sample values from data streams digitized at sampling rates several times the Nyquist Frequency, more valid waveform determination of the sensors data and perhaps a higher Nyquist Frequency could be realized. Some improvement in the waveform determination was found but we were surprised at what happened to Nyquist performance. In practice the Nyquist Frequency turns out to be $\frac{1}{2}$ the lowest repetitive sampling frequency. If we increase the sampling frequency by an integer value, the Nyquist Frequency increases by the same integer number and the analysis software uses each higher integer step in frequency as the basis of its Fourier analysis. Any non-integer time added data values between the lowest regular-clocked sampled values do not increase the apparent sample rate. This finding led us to further investigation of the background parameters involved with the Nyquist criteria and the aliasing phenomenon.

SPECTRAL DISPLAYS

Figure 1 depicts the equipment setup for generating waveforms. Figure 2 depicts the subsystem for data and waveform analysis. Since Fourier analysis is based on sine waves, we started with sine wave modulation of a sine wave carrier. Using 480 Hz for the carrier and an 89 Hz modulation frequency, we obtained the spectrum shown in Figure 3 with a bandwidth of 2,000 Hz.

An oscilloscope trace for the 89 Hz modulated 480 carrier is shown in Figure 4. Please note, there are no spectral lines in Figure 3 above the 480 Hertz carrier plus the 89 Hertz upper sideband ($480 + 89 = 569$ Hz), or below the lower sideband ($480 - 89 = 391$ Hz), except for lower 60 cycle stray pickup peaks.

As we proceed, a convention of designating the clocked digitizing rate as SDR for the Sampled Data Rate currently involved will be adopted, with NSDR denoting the appropriate integer digitizing rate multiple. Bandwidth will become BW and samples per second will become SPS. The SDR convention is considered appropriate because the spectrum of a clocked series of pulses is a series of frequency lines at integer multiples of SDR extending toward infinity. Any SDR spectrum also includes frequencies from DC (direct current voltage or zero frequency) to the initial value of SDR.

Figure 5 shows the spectrum for a series of digitized pulses of a DC voltage sampled at a digitizing rate of 170 sps SDR, in a BW of 1,000 Hz. In effect each of the successive integer spaced spectral lines is its own carrier frequency with its own upper and lower sidebands.

In comparison to the modulated sine wave spectrum of Figure 3, Figure 6 shows the spectrum for an 89 Hz sine wave signal at an SDR of 480 SPS in a 1,000 Hz BW with the cursor marking the lower sideband at 392 Hz (the closest frequency line to 391 Hz). The next peak is at $\text{SDR} + 89 = 569$ Hz and the rightmost analyzer peak at $2\text{SDR} - 89 = 871$ Hz.

Figure 7 shows the spectrum expanded to a BW of 2,000 Hz, the 89 Hz signal peak, a harmonic cursor at the 480 Hz SDR and NSDR integer multiples. The harmonic cursor is seen to fall between successive SDR and NSDR plus - or - minus signal peaks. Obviously the progression would continue toward infinity with alternate SDR - plus - and - minus 89 Hz signal peaks.

So that we do not lose sight of the fact that the plus or minus signal bandwidth about each of the SDR spectral lines includes multiple frequencies, Figure 8 shows the minor spectrum of an 8 Hz triangular wave at zero frequency (baseband) and at either side of the 480 SDR and NSDR rate values. The 8 Hz triangular wave harmonics did not drop off the Db scale between DC and 1/2 the SDR value of 480 sps. This implies activity between 240 Hz and the 480 SPS SDR value. This is in the aliasing frequency range.

NON-REALTIME PROCESSING

Because of the speed of processing with current computers, the spectral analysis programs run quite rapidly. However, the frequency accountability displayed as a result of the analysis is similar to the financial display and review of performance performed by a tax accountant at the end of a customer's fiscal year. This is not a real-time endeavor.

The only activity taking place in real-time is the continuous digitizing data rate sample collection. All of the displayed spectral lines and peaks and valleys are the result of software manipulation of the digitizing data rate measurement values. Also included in non-real-time activity is the aliasing phenomenon which occurs because of the manner in which the Fourier analysis software functions.

Going back to the Nyquist Frequency statement that the sampling rate should be at least twice the highest frequency of interest, the question is of interest to whom? Are the frequencies of interest from DC to 500Hz, 1KHz, 5KHz, or even higher? Whatever signal bandwidth the system designer chooses, he must select an SDR of at least twice that value. In addition he has to decide whether there could be frequency information above the chosen Nyquist value and whether he needs to provide an anti-aliasing filter above that value.

We have already discussed the accuracy of a clocked digitizer. A system designer undoubtedly could find a circuit set, unit, or digitizing board that would run at a digitizing rate up to several mega-samples per second. We have also established that there would be no degradation of the buffered sensors data as a function of the digitizing rate. Therefore, we can choose a 1/2 sampling rate value that will meet our bandwidth and frequency response requirements (with some caveats). In general, the system designer would set his frequency response requirements to define his maximum frequency of interest and then choose an anti-aliasing low pass filter bandwidth to ensure that his frequency requirement would be met. Obviously the choice of filter type, Bessel, Butterworth, etc., will have an influence on his choice. It is interesting to note that most low pass filters require from one to three octaves higher frequency than the three Db corner frequency to get down to a low Db stop band value.

Figure 9 shows the an SDR/NSDR spectrum for a 51 hertz sine wave signal, sampled at 170 sps with the cursor at the $SDR - 51 = 119$ Hz peak. The 51 and 119 Hz frequency are an equally spaced pair either side of the Nyquist value of 85 Hz.

Table 1 lists the sine wave SF=signal frequency, SDR, SDR - & + SF., 2SDR - & + SF., and 3SDR - SF. For the 51/119 Hz and the 43/127 Hz pairs.

SF	SDR	SDR -	SDR +	2 SDR -	2SDR +	3 SDR -
51	170	119	221	289	391	459
119	170	51	289	221	459	391
43	170	127	213	297	383	467
127	170	43	297	213	467	383

TABLE 1

It will be noted that the same frequency peaks appear in each frequency pair but in staggered order. Thus without anti-aliasing filtering, the actual signal could be either of the paired values. While this uncertainty is the basis of the Nyquist phenomenon, it will be noted that the accuracy of the original peak frequencies is still valid, even though some of the data frequencies are above the ½ SDR rate.

CONCLUSIONS

Real time sensor digitized values are accurate samples at evenly spaced time intervals when the digitizer is operated within its specified time and voltage range and is isolated impedance-wise from the sensor. Under these conditions there is no effect on, or interaction with, the sensor or its point by point data progression in either the time or frequency domain.

Frequency analysis is an offline mathematical software procedure performed by the computer on stored sequential point by point digitized values.

The spectrum of the short digitizer pulses for a DC signal is a series of integer lines starting at the digitizer rate (SDR) proceeding towards infinity including a base band component.

For sine wave test frequencies, spectral peaks are the results of lower and upper side bands either side of the SDR and NSDR frequencies without antialiasing filtering. On a test basis, without a priori knowledge, the actual correct peaks can not be positively identified. This is a consequence of the aliasing phenomenon.

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**SIGNAL GENERATION
SUBSYSTEM**

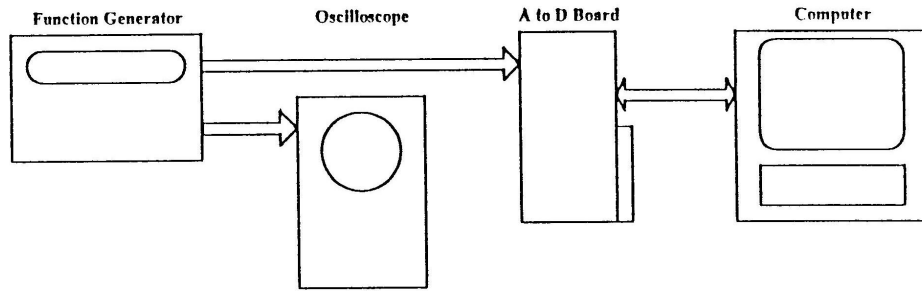


Figure 1

**DISPLAY & ANALYSIS
SUBSYSTEM**

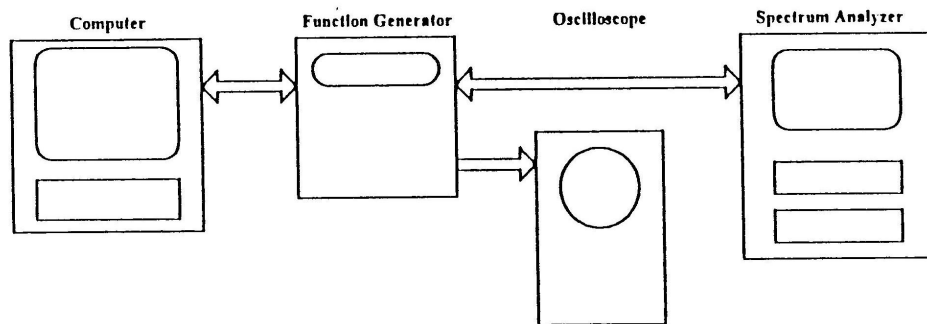
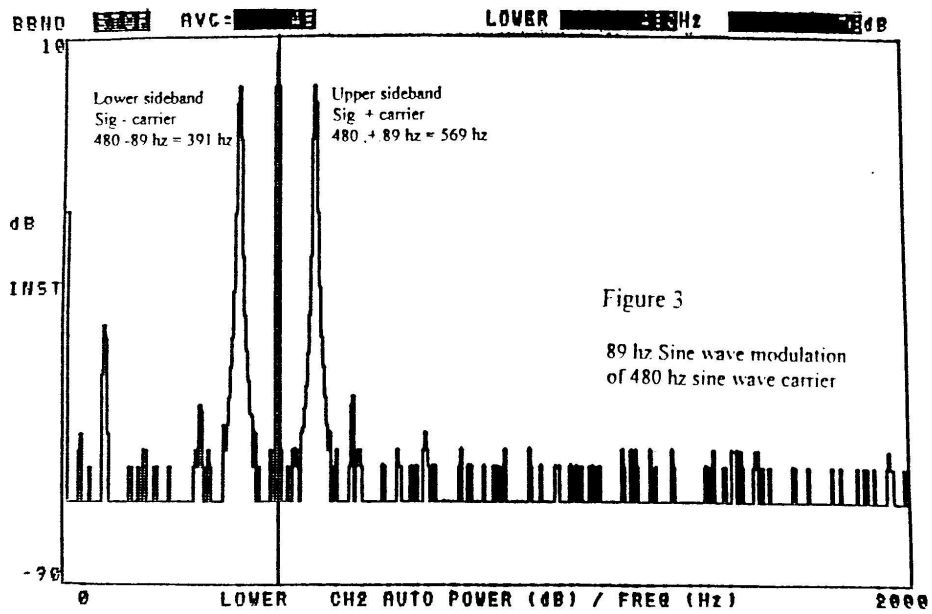


Figure 2



Oscilloscope trace of
89 Hz sine wave modulation
of 480 Hz sine wave carrier
Figure 4

