Time Synchronous Averaging

Introduction

Time Synchronous Averaging (TSA) is a fundamentally different process than the usual spectrum averaging that is generally used in FFT analysis. While the concept is similar, TSA results in a time domain signal with lower noise than would result with a single sample. An FFT can then be computed from the averaged time signal. The signal is sampled using a trigger that is synchronized with the signal. The averaging process gradually eliminates random noise because the random noise is not coherent with the trigger. Only the signal that is synchronous and coherent with the trigger will persist in the averaged calculation, as shown below.

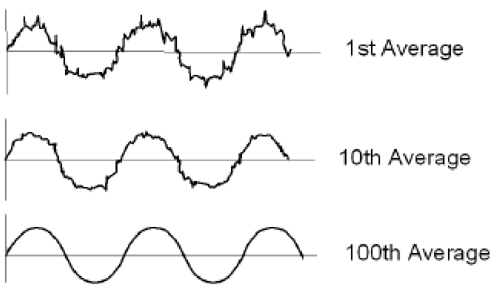


Illustration of the effect of Time Synchronous Averaging.

Traditional spectrum based averaging records a frame of data in the time domain, computes the FFT and then adds the FFT spectrum to the averaged spectrum. The time signal is discarded and then the process is repeated until the averaging number is complete. The result is a spectrum with very low noise, but if you examine each time record that is used to compute the FFT spectra, each time record will include the signal of interest plus random noise because the averaging is performed in the frequency domain, not the time domain.

With TSA the result is a time domain signal with very low noise because the averaging is performed in the time domain, not the frequency domain. In addition you can then compute an FFT of the averaged time signal resulting in a spectrum with low noise. When you compute time domain averaging on a vibration signal from a real machine, the averaged time record gradually accumulates the components of the signal that are synchronized with the trigger. Other components of the signal, such as noise and components from rotating parts of the machine, etc., are effectively averaged out. This is the only type of averaging that actually does reduce noise in the time domain.

Another important application of time synchronous averaging is in the waveform analysis of machine vibration, especially in the case of gear drives. In this case, the trigger is derived from a tachometer that provides one pulse per revolution of a gear in the machine. This way, the time samples are synchronized in that they all begin at the same exact point related to the angular position of the gear. After performing a sufficient number of averages, spectrum peaks that are harmonics of the gear rotating speed will remain while non-synchronous peaks will be averaged out from the spectrum.

Consider a gearbox containing a pinion with 13 teeth and a driven gear with 31 teeth. If a tachometer is connected to the pinion shaft, and its output is used to trigger an analyzer capable of time synchronous averaging, the averaged waveform will gradually exclude vibration components from everything except the events related to the pinion revolution. Any vibration caused by the driven gear will be averaged out because the vibration will occur at different times in every sample relative to the trigger point. The resulting waveform will show the vibration caused by each individual tooth on the pinion. It should be noted that for the special case where the gear ratio is an exact integer, for example 13 teeth on the pinion and 23 on the driven gear, or gear ration of 1:2, then both gears will by synchronized with the tachometer and vibrations from both gears will be exhibited in the TSA signal. However, in general this is not the case.

The figure below illustrates a gearbox with a tachometer and accelerometer signals measured by a signal analyzer with TSA. If the pinion is in good condition then the time signal will show a pulse for each of the 13 teeth and all pulses will be similar as shown in the top signal. If the pinion has a damaged tooth then the pulse associated with that tooth will be different from the others as shown in the bottom signal. Note that if there is a problem with one of the driven teeth it will not exhibit in the TSA signal. However if the tachometer is moved from the pinion to the driven gear then the problem with the driven gear will be exhibited. This technique can be used to identify the location of gear problems in a gear train.

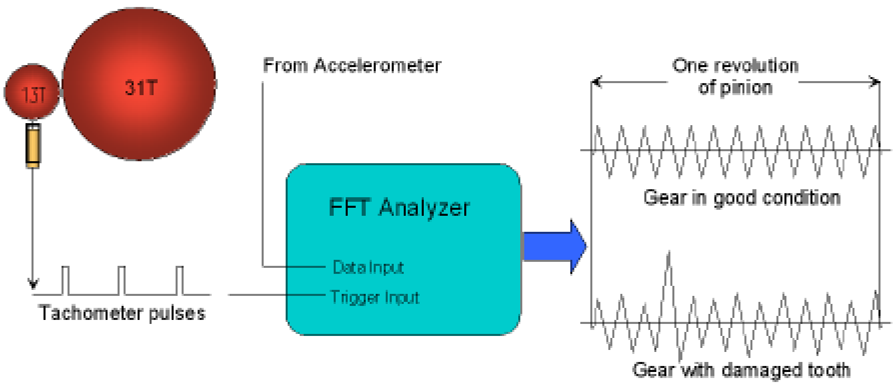


Figure. Illustration of TSA applied to gearbox.

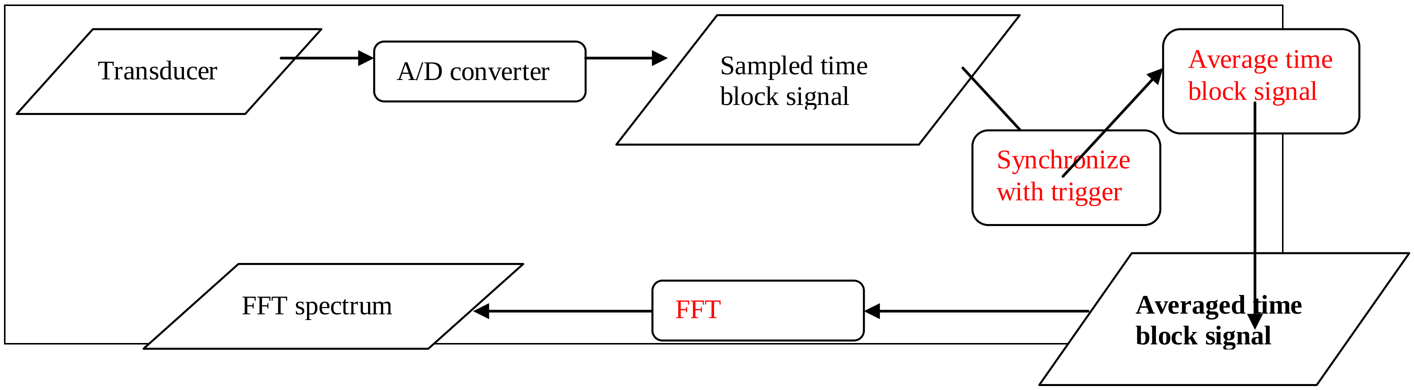
Required Software Options

In CoCo-80, the TSA is currently implemented in Dynamic Signal Analysis (DSA) mode. In DSA mode, time synchronous averaging is available for the following spectra: auto power spectrum (APS), cross power spectrum (CPS), frequency response function (FRF), coherence (COH), and octave spectrum (OCT).

Octave spectrum requires acoustic analysis software package and the other spectra are already included in basic software option.

Algorithm Description

The block diagram below illustrates the TSA process. A signal is measured from the transducer and converted to a digital signal by the A/D converter and sampled in a time block. When a trigger event is measured then the time record is averaged into the averaged time record. Finally the FFT and spectrum can be computed from the averaged time record.



Simplified time synchronous exponential/linear average block diagram

CoCo offers two kinds of time synchronous average: time synchronous linear average and time synchronous exponential average.
For time synchronous linear average the spectrum will stop updating when the average number is reached.

T_n = n^{th} frame of the time block signal
A_n = n^{th} average of the time block signal
N = average number given

For n = 1~N, $A_1 = T_1$.
$A_n = (A_{n-1} *(n-1) + T_n)/n$

n^{th} frame of the spectrum is calculated from A_n.

When the average number N is reached, **the averaged time block signal is**

$$\mathbf{A_N = (A_{N-1} *(N-1) + T_N)/N = (A_1 + A_2 + A_3 + \dots A_{N-1} + A_N)/N}$$

The averaged spectrum is calculated from $\mathbf{A_N}$.

For time synchronous exponential average: spectrum keeps updating and never stops.

$\alpha = 1/N$ = inverse of the average number N
T_{cur} = current frame of the time block signal
A_{cur} = current average of the time block signal
A_{pre} = previous average of the time block signal

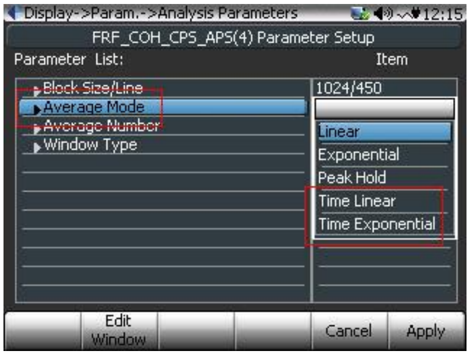
The averaged time block signal is $\mathbf{A_{cur} = (1- \alpha)*A_{pre} + \alpha * T_{cur}}$

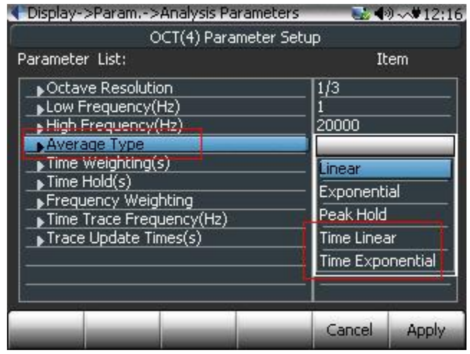
The averaged spectrum is calculated from $\mathbf{A_{cur}}$.

Setup Time Synchronous Average

An APS CSA includes APS spectra, a FRF CSA could include FRF, COH, CPS, and APS spectra, and an OCT CSA includes octave spectra.

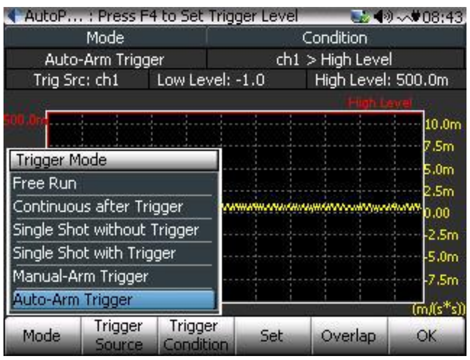
When CoCo is analyzing one of the TSA supported spectra, go to F2: Param ➔ Analysis Parameters ➔ Average mode and select Time Linear or Time Exponential.





Trigger Setup

Configure the trigger using either manual-arm or auto-arm trigger. Refer to the"CoCo80 Basic User Manual.pdf" on your EDM CD or the hammer test example on the page of technical support of supporting site. The two documents give details to help you setup trigger.



Comparison of TSA and Spectral Averaging

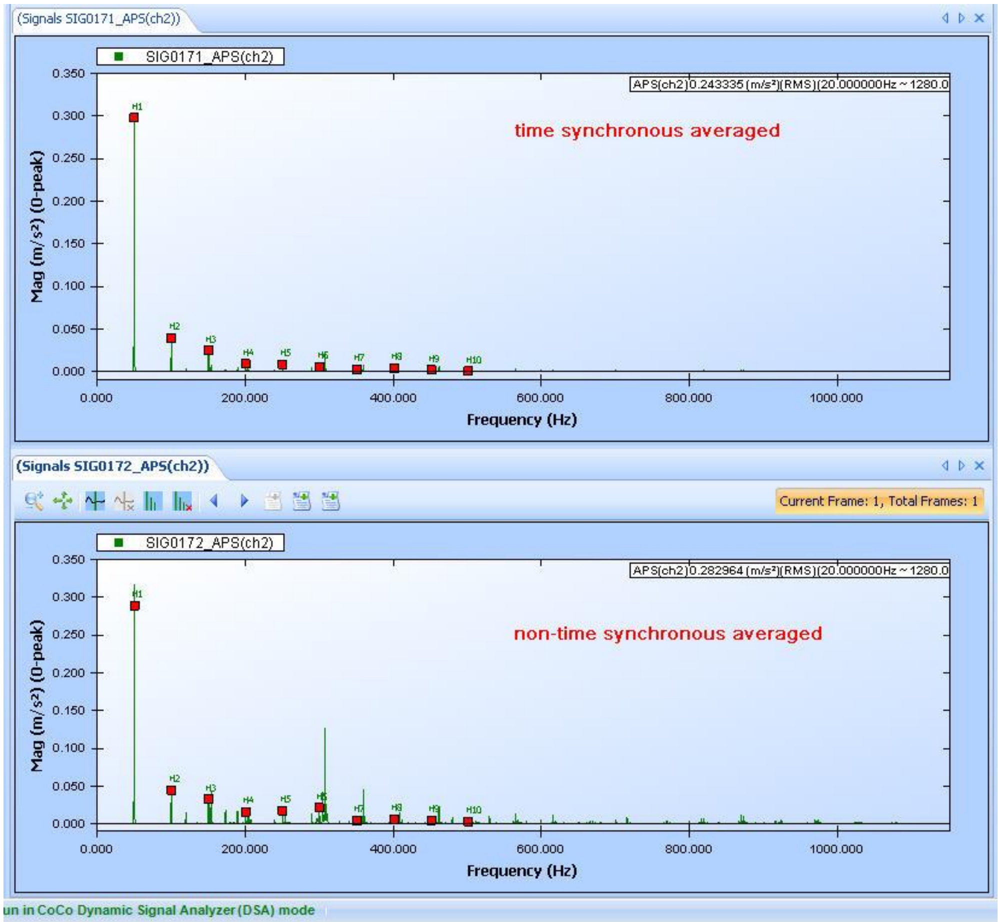
Compare spectrum results of exponential average with time synchronous exponential average

With exponential average applied to the spectrum, noise floor is higher and there are some noise spikes at high frequencies.

With time synchronous exponential average, noise floor is lower and frequencies other than trigger frequency and its harmonics are eliminated during the average process.

From the figure below, red squares are harmonic cursors.

With time synchronous averaging, only harmonic peaks exist in the spectrum and non-harmonic peaks are averaged out.



Conclusion

TSA is an alternative to spectrum based averaging that is useful for some applications especially gear vibration analysis. The averaging is performed in the time domain instead of the usually frequency domain. It is the only method to produce time records with low noise by averaging. It also is useful in identifying the source of vibrations in gear systems. TSA is available in the CoCo-80 in DSA mode.