Impedance Measurement Techniques: Sine Correlation

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There are a number of data acquisition techniques available for the measurement of impedance, these include sine correlation, phase sensitive detectors (lock-in amplifiers), fast fourier transform techniques, lissajous figures and ac bridges. The technique used in the Solartron range of ac instrumentation is digital sine correlation. This technique uses a digitally generated signal to provide fast, accurate measurement over a wide frequency range, upto 12 decades. The correlation technique completely rejects harmonics and dc offsets, and noise effects are significantly reduced by the selection of appropriate integration times. Unlike some of the other techniques mentioned this analysis method is appropriate for both linear and non-linear systems.

For electrochemical measurements where the signal levels are often small (mV and nA), the signals being measured are often buried in noise. The frequency response analysis technique (sine correlation) is excellent at extracting the required signal component from noise. This is achieved by correlating the input signal with reference sine waves and integrating the result over a number of complete cycles of the sine wave. Harmonics are rejected by the correlation process, and noise is rejected by averaging the signal over a number of cycles. Using this technique very small signals can be identified in the presence of very high levels of harmonics and noise. Frequency Response Analyzers (FRA's) usually have separate analysers for each input. This allows fast simultaneous measurements to be achieved. Also, since measurements are taken at exactly the same time on each input (in parallel) any errors due to variations in the signals with time are cancelled.

Solartron FRAs have the ability to analyse harmonic frequencies which can be used to evaluate the non-linearities of a system. One particular method analyses harmonic frequency components to provide a direct estimate of corrosion rate.

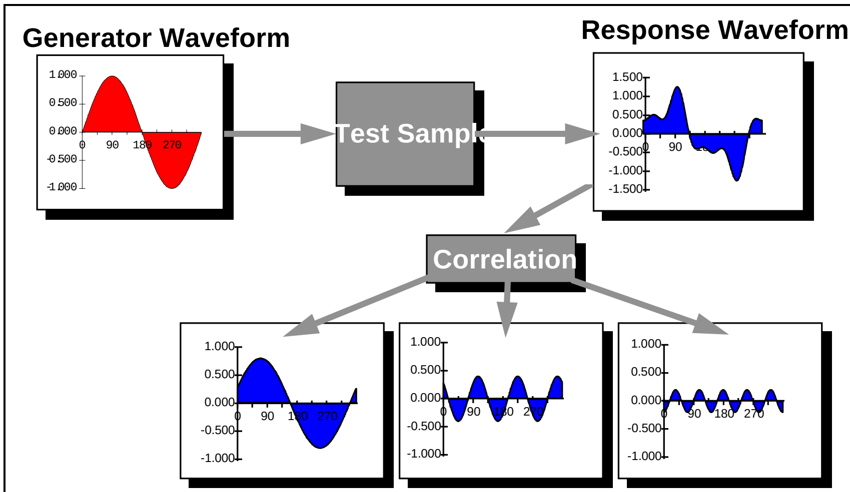

Fig. 1 The Digital Correlation Technique

The Solartron 1250 series use a technique which is called "correlation", to extract harmonic information from the signal being analysed. If a pure sinusoidal waveform is applied to a test cell, the resulting output waveform will often be distorted because the voltage/current relationship is non-linear. Ideally electrochemical tests are carried out with very small AC stimulus signals in order to limit this distortion as much as possible. In some cases though, some degree of harmonic distortion is unavoidable and certainly there will be some noise superimposed due to the low level of stimulus being applied.

The correlation is employed by all Solartron FRA's, a mathematical technique which analyses the generated frequency. For instance the 'response waveform' output from the test item (see Fig. 1), is a distorted waveform containing some second and third harmonic frequency components. The correlation technique identifies each of these frequency components so that the distortion components can either be rejected or analysed to investigate the amount of distortion on the waveform.

One use for measuring the levels of harmonic distortion is in the calculation of the corrosion rate of a sample. By analysing the magnitude of the first three harmonics it is possible to calculate corrosion rate and also the Tafel slopes for a sample.

Solartron Frequency Response Analyzers (see Fig. 2) consist of a sine wave generator which outputs a very pure sinewave of a programmable amplitude and frequency to the test item, and one or more analysers, each of which correlates the input waveform to obtain magnitude and phase information about the analysed signal. Usually one analyser measures the voltage signal between two reference points in the cell and the other analyser measures a voltage waveform which is proportional to the current passing through the cell. Some systems have a single analyzer which is multiplexed to measure these two signals. Only one analyser is shown in the above diagram.

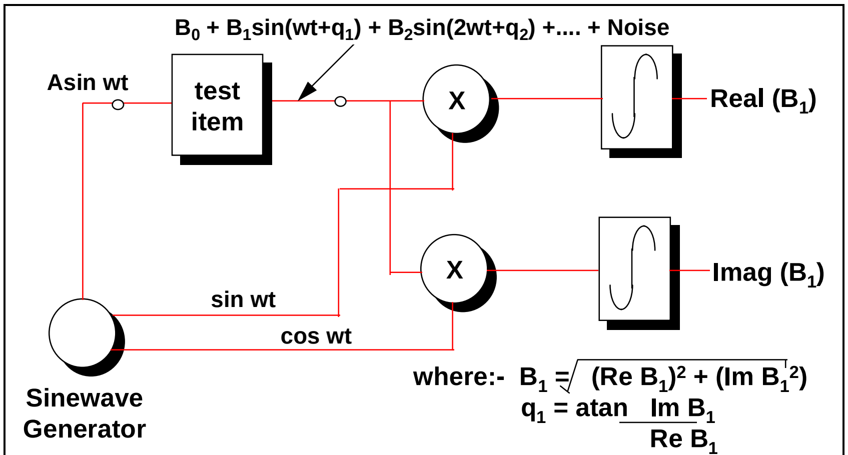

Fig. 2 Schematic of a Solartron Frequency Response Analyzer

The response waveform which is output from the test sample typically has a DC offset (B0 in the schematic above), harmonic distortion components (B2, B3, B4 ....), and noise components generated by the cell or sample. The component of the return signal which is required to be analysed is the B1 component which is at the same frequency as the generator waveform. All of the spurious components of the return signal need to be rejected so that accurate measurements of the fundamental signal component at the generator frequency can be made. Multiplication by reference waveforms and integration is used to filter out these unwanted signals. This process is known as “correlation”.

The result of the correlation process is made up of two components one of which is referred to as the *Real* (or *Inphase*) component, the other is the *Imaginary* (or *Quadrature*) component. By performing simple mathematical operations on these raw measurement results, it is possible to obtain the magnitude and phase shift of the measured signal. From this it is possible to investigate the nature of the sample being tested; for instance a pure resistor gives zero phase shift between the measured voltage and current waveforms whereas a pure capacitor gives a 90 degrees shift.

More complicated cases arise when pure harmonic distortion components are present, the following example shows how these effects are completely removed. The response signal is shown to be 2 volts at 45 degrees (see Fig. 3) and is superimposed with some 3rd and 5th harmonic distortion components. It is possible to see that if some simple rms or peak detection analysis is performed on this signal the results would be distorted by the harmonics which are present.

The results after correlating with sine and cosine reference signals and integrating the result over a whole number of cycles of the waveform is 1.414 volts for both the real and quadrature components. The magnitude and phase is calculated as before from the in-phase and quadrature results, and this gives the final result of 2 volts and 45 degrees phase shift. The distortion components (the 3rd and 5th Harmonic signals), have been totally rejected from the measurements.

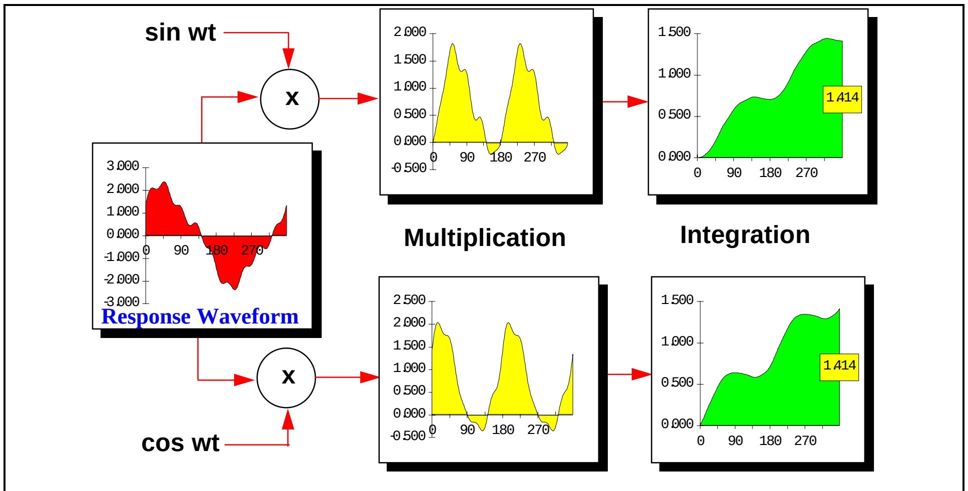

Fig. 3 Complex Digital Correlation

The effect of different integration times on the response of the correlation process which can be regarded as a highly tuneable bandpass filter. The X-axis is frequency relative to the measurement frequency which is normalised to “1” in the above graph. The Y-axis is the response of the filter and is calibrated in dBs (20dB is equivalent to a 10 times increase or reduction in signal amplitude).

If one cycle of the waveform is analysed then the upper line represents the response of the correlation filter. One can see that even with only one cycle of integration all harmonics are rejected (there are notches in the response line at 2,3,4, ... times the measured frequency). Also if the graph is extrapolated back to 0 frequency the response is also zero (i.e. DC offsets are also rejected). However, if only one cycle of integration is used then if there is any noise on the input signal at for instance 1.1 times the input frequency, then this will be added into the result and will not be significantly rejected, this may produce noisy results.

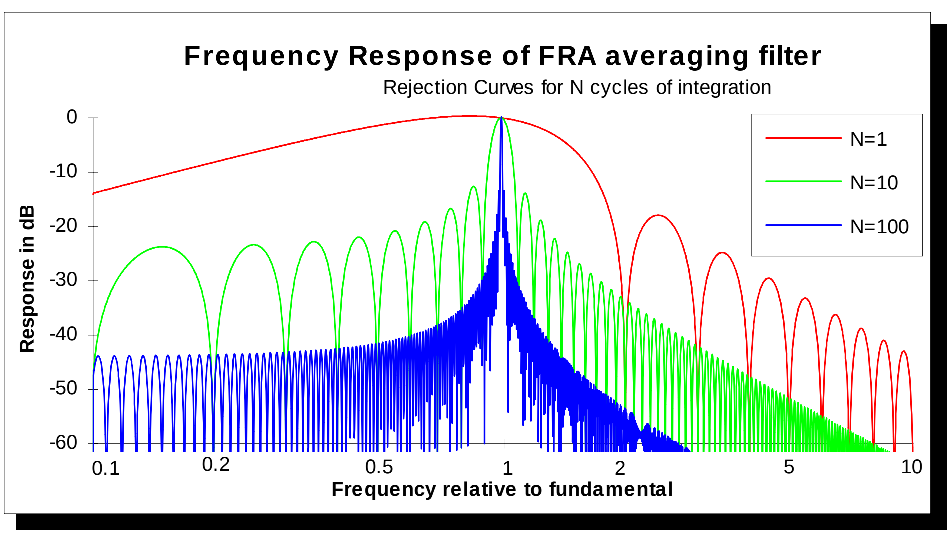

Fig. 4 The effect of integration times on the correlation process

The second line (N = 10) represents the filter when 10 cycles of the input waveform are integrated. In this case, not only are the harmonic frequencies rejected, but 10 sub-harmonic frequencies between each of the main harmonics are also fully rejected. Also any noise which is on the input waveform is now rejected by a factor of 10 (20dB). Similarly for 100 cycles of integration, 100 sub-harmonics between each of the main harmonics are fully rejected, and the general noise background is rejected by a factor of 100 (40dB). Therefore to reject noise from the measurements it is necessary to increase the integration time. The measurements are increasingly more stable as integration time is increased, but of course the experiment will take longer to run.

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