

# Intelligent multi-sine EIS measurement

### Intelligent Multi-sine EIS

Electrochemical impedance spectroscopy (EIS) is a main characterization tool in the field of electrochemistry. EIS measurements are usually carried out over a broad frequency range ( $\mu\text{Hz}$  to  $\text{MHz}$ ). At low frequencies, the total measurement time increases drastically. A single impedance measurement at  $1\text{ kHz}$  will take  $1\text{ ms}$  but a single impedance measurement at  $1\text{ mHz}$  requires nearly 17 minutes and a single impedance measurement at a frequency of  $10\text{ }\mu\text{Hz}$  requires more than 27 hours to complete. An EIS measurement over low frequencies can last days. A method is needed which can decrease the overall measurement time for the EIS measurement at low frequencies.

To avoid long measurement times, Zahner's Thales software allows multi-sine EIS measurements at low-frequency range ( $f < 100\text{ mHz}$ ) via exciting multiple sine signals simultaneously (see Fig. 1). The EIS data at high frequencies is always measured with single sine excitations as it offers better signal to noise ratio. During the EIS measurement, discrete Fourier transformation (DFT) is used to evaluate the excitation and response signals in real time. Using DFT, the effect of non-stationaries is minimized in single-sine and multi-sine EIS measurements via real-time drift compensation and error calculation.

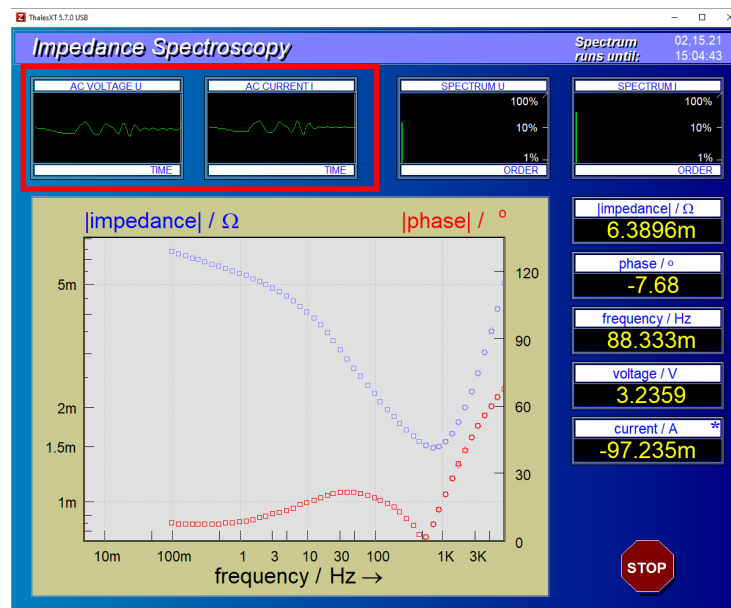


Fig. 1: Multiple sine excitation and response during multi-sine EIS measurement (see red box).

For multi-sine EIS measurements, the system under investigation must be stationary. A non-stationary system (i.e., with high drift) will result in noisy EIS spectrum.

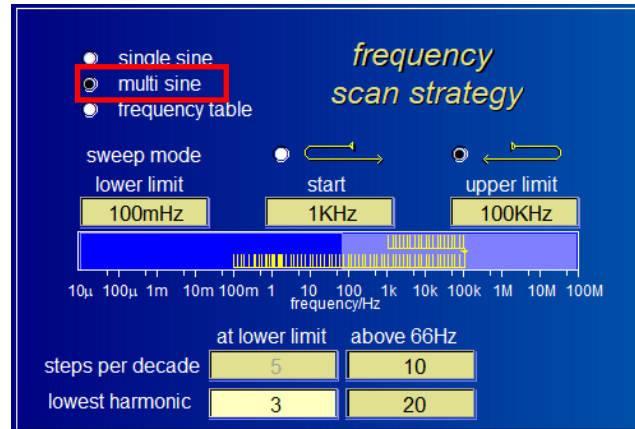


Fig. 2: Multiple sine EIS settings

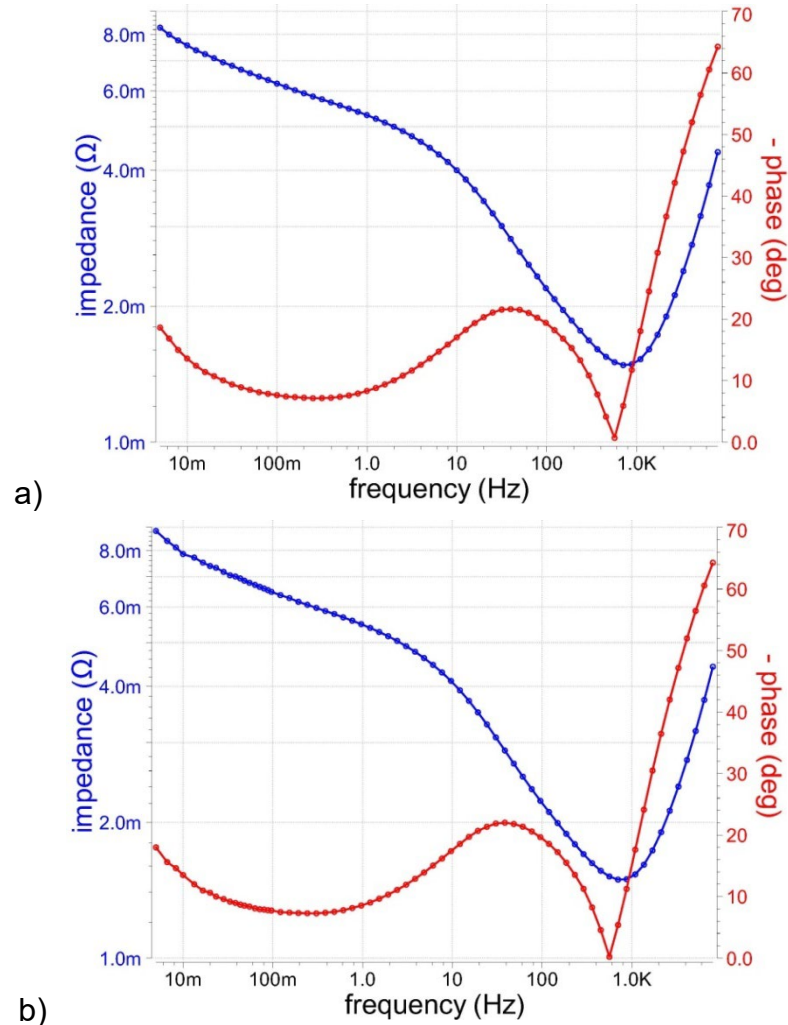
The table below is taken from Zahner's [EIS manual](#) and shows the minimum measure periods required for the real-time drift compensation and error calculation for different frequencies.

Measure period count effect on the quality of <i>iMS</i> :			
measure period	$\geq 3$	2	1
available from lower frequency limit [Hz]	$\leq 100\text{m}$	$\leq 66\text{m}$	$\leq 33\text{m}$
real-time drift compensation	fully	fully	fully
error calculation	fully	partially	partially

Table. 1: Measure periods required for complete real-time drift compensation and error calculation.

The Fig. 3 shows multi-sine EIS spectra measured for a 40 Ah battery. The battery was continuously discharged with a small discharging current of -100 mA. An AC excitation signal of 500 mA amplitude was used for the EIS measurement. A single-sine EIS spectrum was also measured with the same measurement parameters as a standard measurement and to compare the multi-sine measurement with the single-sine measurement.

The similar single-sine spectrum (Fig. 3(a)) and the intelligent multi-sine spectrum (Fig. 3(b)) depict the good performance of the iM-sine. The measurement of single-sine EIS spectrum and intelligent multi-sine EIS spectrum required 167 minutes and 44 minutes, respectively, proving that iM-sine can decrease the measurement time without compromising on the measurement quality.



**Fig. 3:** a) Single sine EIS spectrum and b) intelligent multi-sine EIS spectrum measured on a 40 Ah battery. At low frequency range, more than 3 “measuring periods” were chosen for both measurements to activate the real-time drift compensation and error calculation.

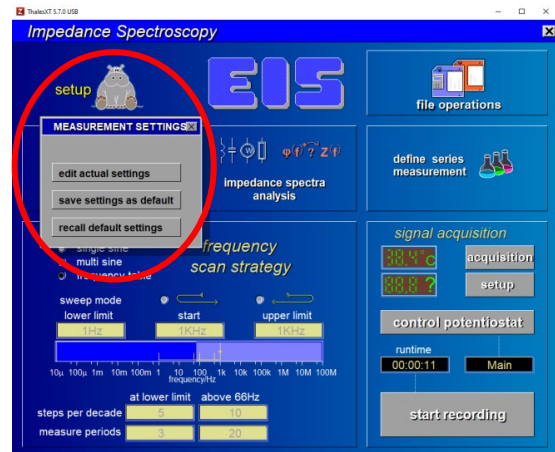
In iM-sine, up to 20 sine signals are excited simultaneously and the excitation amplitude is divided between the 20 excitation signals. Hence in iM-sine, the signal to noise ratio is usually less at low frequency range. Therefore, it is very important that the user should set as high excitation amplitude for iM-sine EIS measurement as possible without causing non-linearity to improve the signal to noise ratio.

### Setting up drift compensation

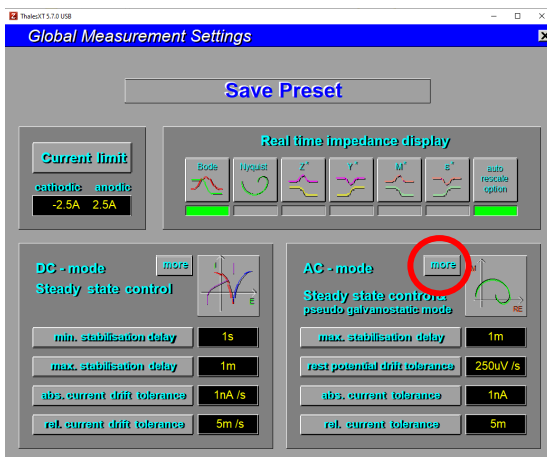
Before starting the iM-sine EIS measurements, make sure that the drift compensation is activated in the Thales software. To activate the drift compensation, follow the steps provided below.



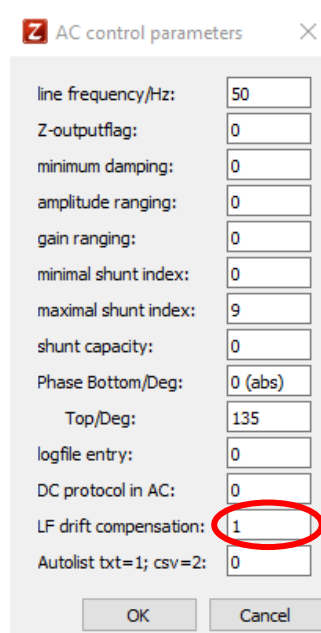
1. Click on EIS.



2. Click on setup → edit actual settings.



3. Click on more in AC- mode.



4. Enter LC drift compensation=1  
Click OK.