LIA in a Nut Shell: How can Trigonometry help to understand Lock-in Amplifier operation?

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Abstract

Taking into account the actual need and importance of introducing fundamental concepts related to the detection of small and noisy electrical signals in the curriculum of physics and engineering studies, in this work a simple trigonometric analysis often encountered in mathematics class room's exercises will be used to show a simple manner to familiarize students at basic undergraduate college and university level with the basic principles of the Lock-in Amplifier, an instrument widely used in research laboratories for the measurement of AC signals modulated at a given frequency in an environment of very low signal to noise ratio.

Keywords: Electronic measurement, electrical noise, lock-in amplifier, trigonometry.

Resumen

Teniendo en cuenta la necesidad y la importancia de introducir en el currículo de estudio de física e ingeniería los conceptos fundamentales relacionados con la detección de señales eléctricas pequeñas y ruidosas, en este trabajo utilizaremos un análisis trigonométrico sencillo, muchas veces encontrado en ejercicios de aula de matemática, para mostrar una manera relativamente simple de familiarizar a los estudiantes de pregrado con los principios básicos del Amplificador Lock-in, un instrumento ampliamente utilizado en laboratorios de investigación para medir señales de corriente alterna a determinada frecuencia, en un ambiente de muy baja relación señal-ruido.

Palabras claves: Medición electrónica, ruido eléctrico, amplificador lock-in, trigonometría.

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The use of trigonometric identities is an important aspect in mathematics, sciences and engineering courses. Often become important to talk students about possible applications of the problems they solve in class rooms. This can serve as motivation and to make them familiar with the fundamentals of the instruments and the phenomena that they can find in their surrounding world. Thus, here we will briefly show how the solution of such a problem should be a good exercise to anticipate the notion of Lock-in detection since introductory trigonometry courses. This is important because we have witnessed in the last years the widespread and routine use of the so-called Lock-in amplifiers (LIA) in research and educational laboratories to detect and measure very small and noisy AC signals, therefore it becomes necessary to familiarize physics and engineering students since the first years of learning in high-schools, colleges and universities with their basic principle of operation, in the same way as they become familiar with other more traditional electrical signals measurement instruments such as galvanometers, conventional voltmeters, oscilloscopes and so on.

A LIA can be defined as an instrument that permits the measurement of AC signals modulated at a given frequency, *f*, in an environment of very low signal to noise ratio. The main function of LIA is then to measure the component of the signal at *f* and reject noise signals at other frequencies. Thus, in addition to the signal input one also needs to provide a LIA with a reference input containing a wave form (often a sinusoidal wave) at the reference frequency to "lock in" the response from an experiment at this frequency and to ignore anything that is not synchronized with it.

Although several experiments have been proposed to include this instrument in undergraduate experimental courses [1, 2, 3, 4, 5, 6], perhaps one of the most simplest exercise that can be implemented to demonstrate the advantages of lock-in detection is to modulate a light emitting diode (LED) with a square wave using a simple