TeachSpin's Fourier Methods
A Conceptual Introduction to the Experiment

Everyone is used to the idea of information being carried by 'signals' such as acoustical waves, light rays, mechanical vibrations, or electrical impulses. And nowadays most of these can be converted into electronic waveforms, and viewed on an oscilloscope to give a plot or graph of a voltage-vs.-time, $V(t)$. But there are many signals whose content is most clearly revealed, not in this sort of 'time-domain view', but instead after sorting by *frequency content*. The result is a spectrum, or a 'frequency-domain view', of the information content of a signal. **Fourier Methods** is the name of a product innovation from TeachSpin seeking to make this frequency-domain understanding as much a part of students' (and teachers') mental equipment as the more familiar time-domain view.

Most people know how (in the regime of optical signals) waves can be sorted out, or analyzed, into their separate wavelength or frequency components using tools such as prisms or gratings. In the realm of electrical signals, there are alternative methods. One of the best of them involves waveform capture by voltage sampling and digitization, followed by the mathematical operation of the Fourier transform, to analyze the waveform into its frequency components. For electrical signals of not too high a frequency, this can be done in real time, giving a Fourier spectral display. TeachSpin's new offering is centered around the SRS770 'FFT Analyzer', which can continuously display the spectral content of electrical signals in the 0-100 kHz range (or any sub-part of that frequency band).

Simultaneously viewing a signal with an oscilloscope and the Fast Fourier Transform (FFT) analyzer is the best way to develop an intuition for how 'time-domain' and 'frequency-domain' views of a signal are related. The simplest signal of all is a single sinusoid, whose Fourier transform reveals single spectral line; its location on a frequency axis gives the frequency, and its height gives the amplitude, of the signal in question. What's remarkable is that if the single sinusoid is replaced by any superposition of multiple sinusoids, the single-line spectrum is replaced by a multi-line spectrum, allowing a *simultaneous* view of all of the spectral components. It also allows the simultaneous measurement of the various amplitudes, even if they differ by a factor of 10^4 or more (offering a dynamic range much larger than a typical oscilloscope).

Other signals have waveshapes more complicated than sinusoids. Periodic signals have Fourier series expansions, which means their Fourier spectra consist of a fundamental frequency plus harmonics at its integer multiples. A Fourier spectrometer makes the decomposition into harmonics visible at a glance, and instantly shows how periodic waveforms of identical frequency and amplitude can nevertheless be distinguished (for example, by the ear) due to their different harmonic content.

One of the major themes of information transfer is the concept of a 'carrier wave' that is modulated to convey information. Fourier Methods includes the electronic tools that students need to form modulated waveforms, and to view their spectra by Fourier analysis. It shows in detail how amplitude modulation and frequency modulation can be accomplished, and how AM- and FM-waveforms have spectra which differ from that of the un-modulated carrier wave. It also gives students the tools for *de*-modulation of AM and FM waveforms, including all the modules needed to build a working AM receiver.

There are also signals which are not periodic at all, *noise* waveforms chief among them. Such waveforms also have Fourier spectra, but they are *continuous spectra* rather than line spectra. The SRS770 makes the quantitative measurement of noise feasible, via its view of these continuous spectra. The experiments' Manual teaches students how to use the 770 to make quantitative measurements in that novel unit, the V/√Hz. The TeachSpin electronics also includes an electronic noise source, and further offers students an encounter with the 'buried treasure' of single-frequency signals deeply submerged under noise, yet still detectable via Fourier analysis. The TeachSpin package also includes an analog-electronics realization of the Lorenz strange attractor, so that students can study the Fourier spectra of *chaotic* waveforms.

The study of Fourier methods in the lab really works best if students have direct hands-on access to real-time working circuits and devices they can configure, and we've included a wealth of them among our Electronic Modules. Each module illustrates some capability of signal processing, and makes it possible to see what it does to signals in the time and the frequency domains. In addition to these Modules, the package includes some hardware experiments: an Acoustic Resonator, a Fluxgate Magnetometer, and a Coupled-Oscillator system, each of which illustrates the power of the Fourier methods for understanding the physics of the situation. The skills the students learn on these modules and experiments are highly transferable, and the entire package is open to the importation of signals from anywhere else in the lab for analysis.