Forecast:
Breath of fresh air!

The Relaxation Times

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VOL. IV No. 11 ***NEWSLETTER OF TEACHSPIN, INC.*** ***July 2015***

TEACHSPIN WELCOMES CARL GROSSMAN

TeachSpin's stars must have been aligned to bring us a new 'Marketing Director' with qualifications and talents that are such a perfect fit. It is with great pride that we announce the arrival of Professor Carl Grossman of Swarthmore College as the newest member of the TeachSpin Team! We must be doing something very right for Carl to be joining TeachSpin to create a new and expanded marketing program. (In case you were wondering, Barbara will continue on, but will focus more on Undergraduate Laboratory Consulting.) To say we are excited understates the mood at TeachSpin.

Carl spent 25 years as a member of the physics faculty of Swarthmore, one of the outstanding liberal arts colleges in the United States. He was part of a departmental team that collaborated to create a truly impressive advanced laboratory. Our first-hand knowledge of the program comes from many visits to the campus where we spent quality time exploring the facility and meeting both faculty and students. (Barbara is Swarthmore alum.) In its array of home-built and commercial apparatus, Swarthmore's advanced lab includes several TeachSpin Instruments used both in the Advanced Lab setting and for individual student projects.

Carl's research career in physics has touched on many areas, most of them connected to or facilitated by modern optics. He's worked on ultrafast lasers and their use in single-molecule studies; he's worked on second-harmonic generation in non-linear optics; he's worked on autocorrelation studies in molecular fluorescence; he's worked on photon echoes. Which of these do you suppose might turn up first in a TeachSpin instrument?

Carl received both his undergraduate and graduate degrees from the University of Pennsylvania. His PhD thesis, "Experimental Studies of Second Order Nonlinear Optical Susceptibilities in Organic Single Crystals", launched his career in the field of optics. Over his years at Swarthmore, he was awarded various grants including a Fulbright Scholars Award in 1999. Since 2005, he has devoted much of his summer to mentoring in the Science for Kids Outreach Program and, since 2012, has served as its director. This is an inner city outreach program funded by a grant from the Howard Hughes Medical Institute.

We also know Carl through his activities in ALPhA. Most recently, he was one of the inaugural ALPhA Miners prospecting for advanced lab possibilities in the vast array of talks at the 2015 APS March Meeting. His was the first report delivered to Miners editor David Van Baak.

Although his official title will be 'Marketing Director', Carl, as our third academic PhD physicist, will also be involved in instrument development and available to answer technical, theoretical, and instructional questions about your TeachSpin apparatus. He will be sharing with all of us the insights gained in 25 years of developing experiments, designing instruments, creating instructional materials, and working with students in an outstanding advanced lab. Carl will be part of the new generation, the new energy, here at TeachSpin!

Diagnosing Noise: A Case Study

If you know about the product offering ‘Fourier Methods’ from TeachSpin, you know that it’s centered around a highly capable instrument, the SR770 ‘FFT Spectrum Analyzer’ from Stanford Research Systems. But in addition to serving as the centerpiece of this fine new laboratory curriculum, the SR770 has become an everyday benchtop tool in development work at TeachSpin. We think it can do the same for your laboratory investigations! What follows is a real-life case study illustrating the insight that the use of a Fourier-analysis tool can deliver – it comes from diagnostic work on our ‘Optical Pumping’ apparatus.

Optical pumping is a classic phenomenon in atomic spectroscopy that makes visible the effects of driven *radio*-frequency quantum transitions in atomic systems. All the results from such experiments come from monitoring changes in the intensity of transmitted light. In our case, that light is the 795-nm resonance radiation produced in a rubidium spectral lamp. The light is then passed through a cell containing a vapor of ground-state rubidium atoms. Under one set of operating conditions, about 12 μW of 795-nm light passes through that Rb vapor cell, and falls onto a silicon photodiode, where it produces a measured 6.6 μA of steady photocurrent. In a pre-amplifier, this current gets converted (at rate 1 V per μA) to a 6.6-V dc signal, and all the subsequent optical-pumping experiments then depend on seeing (small) changes in that dc voltage. (In this context, a 2% dip in that dc value represents the detection of a strong transition. Weak but still-detectable transitions cause changes smaller than 25 parts per million.)

Clearly, any such changes have to be detected in competition with the **noise** level of that 6.6-V dc signal. So the Optical Pumping apparatus applies the usual strategy of subtracting a constant from the signal level, and then amplifying any deviations, to produce an output signal. Fig. 1 shows an oscilloscope trace of the result of such a tactic of ‘zero suppression’ and 100-fold amplification.

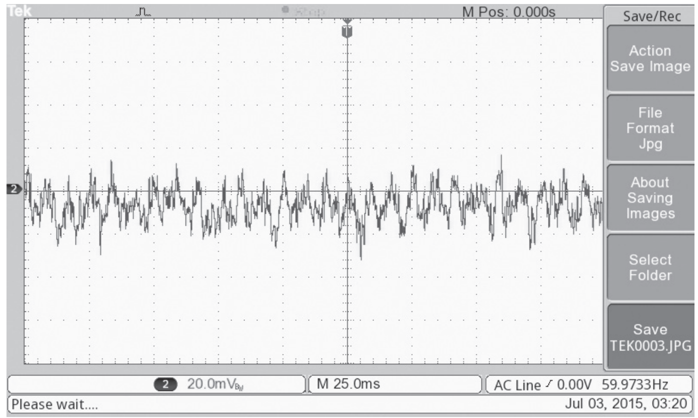

Fig. 1. Oscilloscope’s view, at 20 mV/div, of the result

That gives a **time-domain** view of the voltage (and its noise) against which any signal of interest will have to be detected. Wanting to understand, quantify, and analyze that noise background, we sent that zero-suppressed signal into our SR770 FFT analyzer to display its frequency spectrum. The result, shown with a logarithmic vertical scale, is a **frequency-domain** view that is *much more informative* than the ‘scope trace!

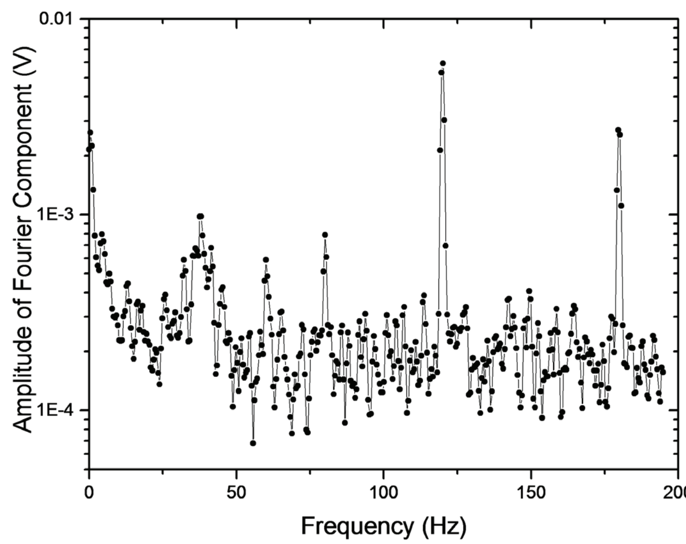

Fig. 2. Frequency-domain view of the same signal

Here’s what we discovered:

a) The broad-band noise contains narrow-band features. The most prominent is a spectral peak lying at a tell-tale frequency of 120 Hz; it also diminishes when we turn off the room lights. We conclude it comes from 120-Hz fluctuations in the ambient (fluorescent) lighting, leaking through our light shielding and reaching the photodetector.

b) The next most prominent peaks in Fig. 2 lie at the frequencies 60 and 180 Hz, and we note they also are line-frequency related. Because they are found not to depend on ambient light, we conclude that these interference features are coupled into the system magnetically, rather than optically.

c) The use of a running-average filter, of time constant $\tau = 10$ ms, slows the time response, and also narrows the frequency bandwidth, of the signal. In the noise spectrum shown in Fig. 3, this shows up as a 'rolling off' in the frequency response above a corner frequency of $1/(2\pi\tau)$, or about 16 Hz in this case. This reduces the effects of the 60- and 180-Hz interference.

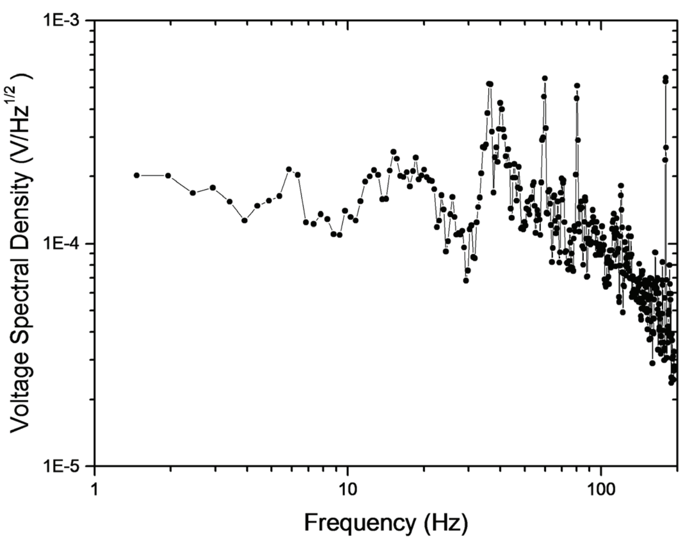

Fig. 3. Voltage spectral density after filtering

d) But underneath those now-understood spectral peaks, the SR770 reveals the non-zero 'noise floor' out of which they rise. It is a frequency-independent noise floor, so we conclude that there is 'white noise', as well as periodic interference, in the optical-pumping signal. (Blocking the 795-nm light path markedly reduces this noise-floor level, showing that noise *in the light intensity itself* dominates over pre-amplifier and other electronic noise.) Crucially, the Fourier spectrum shows that the noise floor is *spectrally flat* right down to frequency 1 Hz, so the signal is largely free of the 'excess noise', or $1/f$ noise, which would otherwise make it difficult to detect small changes in the dc output level.

e) And unlike an oscilloscope, the SR770 can *quantify* the 'voltage spectral density' of that noise floor. We measured a result, near 155 μV/√Hz, right off the display in real time.

From these measurements, we infer that upstream of the dc-coupled amplification by 100-fold, there was a 1.55 μV/√Hz noise density atop that 6.6-V dc signal. We conclude that the 6.6-μA photocurrent carried noise with a 'current spectral density' of 1.55×10^{-12} A/√Hz, whose square gives the 'power spectral density of current noise', $S_{meas} = 2.4 \times 10^{-24}$ A^2/Hz. This is the number, finally, that can be compared to the ***shot noise*** that's predicted to be present in a 6.6-μA photocurrent, derived as it is from the rain of independent photons onto the photodetector. The textbook prediction for shot noise density is

$$S_{pred} = 2\, e\, I_{dc} = (3.2 \times 10^{-19}\ \mathrm{C})\,(6.6 \times 10^{-6}\ \mathrm{C/s})$$
$$= 2.1 \times 10^{-24}\ \mathrm{C^2/s} = 2.1 \times 10^{-24}\ \mathrm{A^2/Hz}.$$

Conclusion: the agreement between S_{meas} measured in our Optical-Pumping apparatus with the predicted value S_{pred} from shot-noise theory shows that basically the *whole* of the experimentally-observed noise floor can be attributed to shot noise. This kind of noise dominates, in this case, over Johnson, amplifier, and technical noise. Our spectral-lamp source is thus confirmed to be *shot-noise-limited*, displaying as little noise as is consistent with the random emission of independent photons. In simpler terms, this is as 'quiet' a light source as can be built.

Calculations like this can even be turned around, to ***find***, rather than to use, the numerical value of *e*. We've taken advantage of this idea in our 'Noise Fundamentals' apparatus. One of its (many) capabilities is to allow the creation of dc photocurrents I_{dc} ranging from 0.001 to 100 μA and more, and to enable the measurement of the current noise density S that lies atop them. Then the equation $S = 2\, e\, I_{dc}$ can be tested (quantitatively, and over several orders of magnitude) for its I_{dc} -dependence, and a numerical value of the fundamental charge e can be extracted from the results. That's a remarkable return from what starts out looking like 'mere electronic noise'!

Implications: Given this case study highlighting the kinds of qualitative insight, and quantitative results, that can be acquired using a proper spectrum analyzer, what sorts of problems in your lab could you solve with this sort of tool? And what sorts of insights and experiences in 'Fourier thinking' could your students then take with them from your lab courses?

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Introducing TeachSpin's New Marketing Director

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Diagnosing Noise: A Case Study

ALPhA Immersions continue: Have you bookmarked http://www.advlab.org/immersions.html ? That site tells you about ALPhA Immersions, the premier way for you to learn, in hands-on fashion, a new laboratory experiment or technique that you can then teach with confidence. There are more Immersions this August, and another full slate is being planned for 2016. These Immersions are bargain-priced, two- and three-day experiences of professional development, taught by your peers, in which you can participate in the *learn-by-doing* way of understanding a new lab experiment, technique, or apparatus.

The **Jonathan F. Reichert Foundation** has a website too: http://jfreichertfoundation.org. This non-profit Foundation is not only the new owner of TeachSpin, Inc., it is also already active in its core mission – ***Enhancing Advanced Laboratory Physics Instruction.*** The Foundation has budgeted money to help subsidize, at US institutions, the replication of experiments that participants learn at Immersions. Look under the Foundation's GRANTS & PROGRAMS tab for 'ALPhA Immersion Support' and see if your Immersion experience might qualify you for funding of apparatus!