Forecast:
The Noise is
Worth the Listen
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The Relaxation Times

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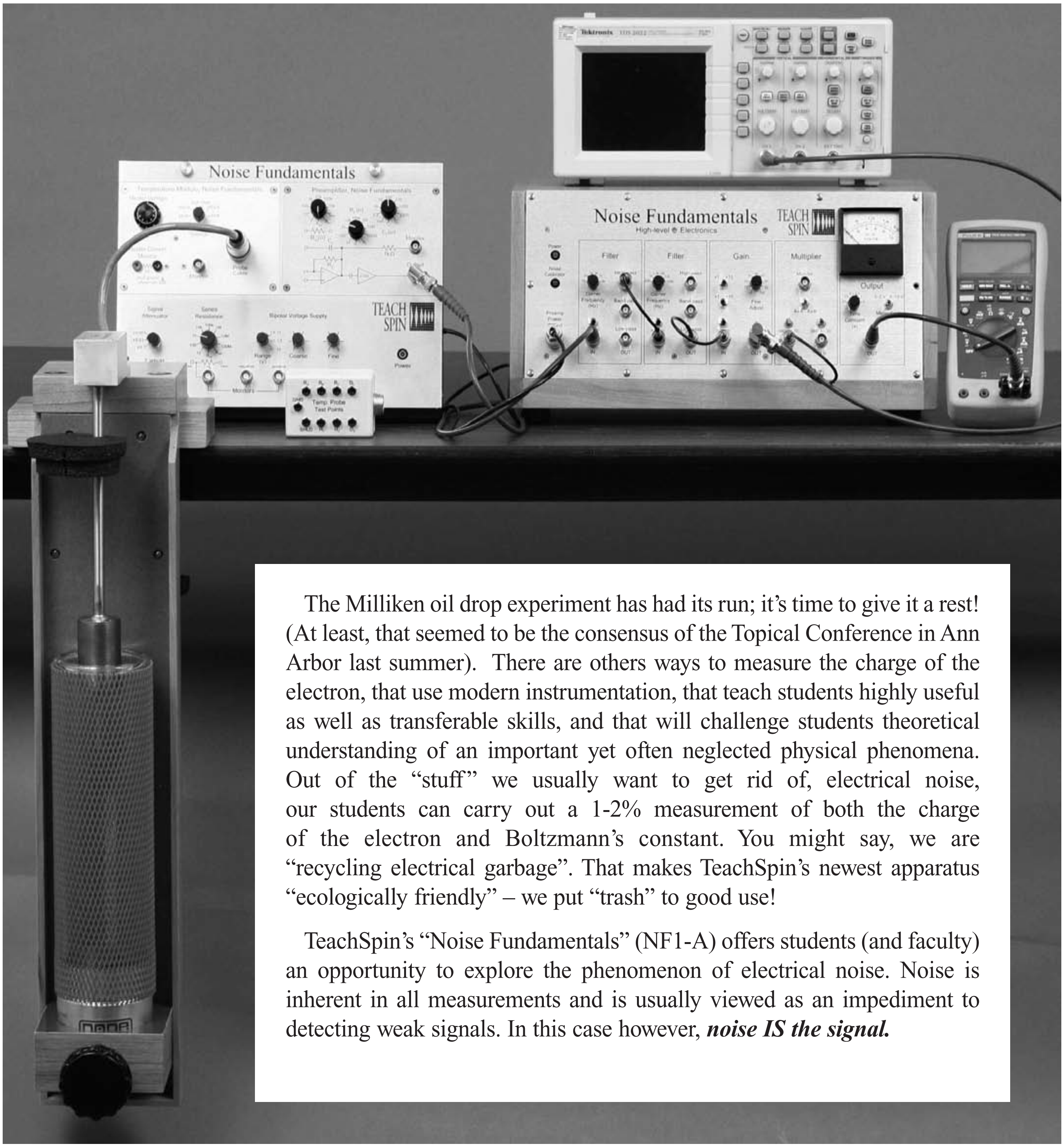
NOISE FUNDAMENTALS

"Where Noise IS the Signal"



The Milliken oil drop experiment has had its run; it's time to give it a rest! (At least, that seemed to be the consensus of the Topical Conference in Ann Arbor last summer). There are others ways to measure the charge of the electron, that use modern instrumentation, that teach students highly useful as well as transferable skills, and that will challenge students theoretical understanding of an important yet often neglected physical phenomena. Out of the "stuff" we usually want to get rid of, electrical noise, our students can carry out a 1-2% measurement of both the charge of the electron and Boltzmann's constant. You might say, we are "recycling electrical garbage". That makes TeachSpin's newest apparatus "ecologically friendly" – we put "trash" to good use!

TeachSpin's "Noise Fundamentals" (NF1-A) offers students (and faculty) an opportunity to explore the phenomenon of electrical noise. Noise is inherent in all measurements and is usually viewed as an impediment to detecting weak signals. In this case however, ***noise IS the signal.***

The thermal noise of a resistor, called Johnson noise, is used to determine Boltzmann's constant, $V_n^2 = 4\ RkT\Delta f$ and current noise of an illuminated photodiode (or other devices) called shot noise, can be used to measure the charge of the electron, $I_n^2 = 2\ e\ I_{AVE}\ \Delta f$.

Noise Fundamentals has three main elements; low-level electronics, high-level electronics, and a variable temperature probe. Figure 1 shows a close-up of the low-level components. Enclosed in this cabinet are an ultra-quiet bipolar power supply, a calibrated signal attenuator, a variable temperature "plug in" module, and a low-noise preamplifier "plug in". The attenuator is used in conjunction with a user supplied signal generator to calibrate the gain and bandwidth of various stages of amplification. The switch selectable resistors convert the voltage source to a current source for proper operation of the pn diodes, led's or Zener diodes used in the shot noise experiments.

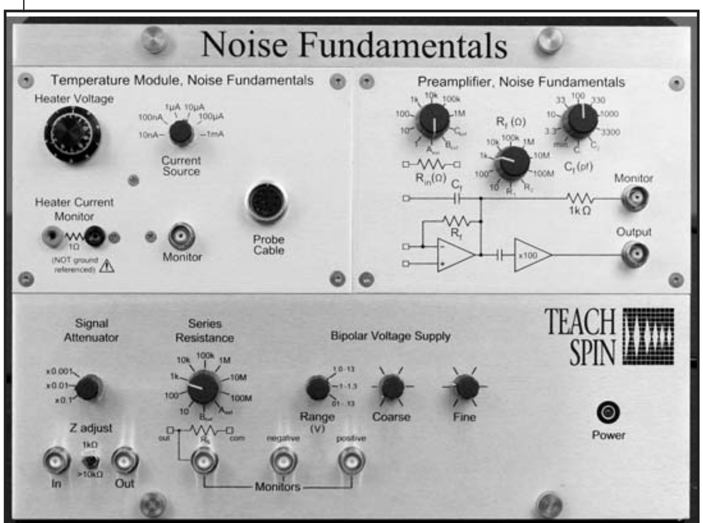


Fig. 1 Low-level electronics control panel

Students must configure the "front-end" electronics for each experiment. This includes the bias voltages or currents, as well as the first stage of amplification. The front panel can easily be disconnected and flipped to expose the backside as shown in Figure 2. Terminal blocks on the circuit board are available for the students to insert the proper component or jumper wires. This is the first TeachSpin apparatus that allows (requires) students to configure the electronics for their measurements. Thus, NF1-A provides the opportunity to learn *both* physics and basic electronics. Operational amplifiers are used for all gain stages, but the first stage preamplifier is designed to be configured by the student.

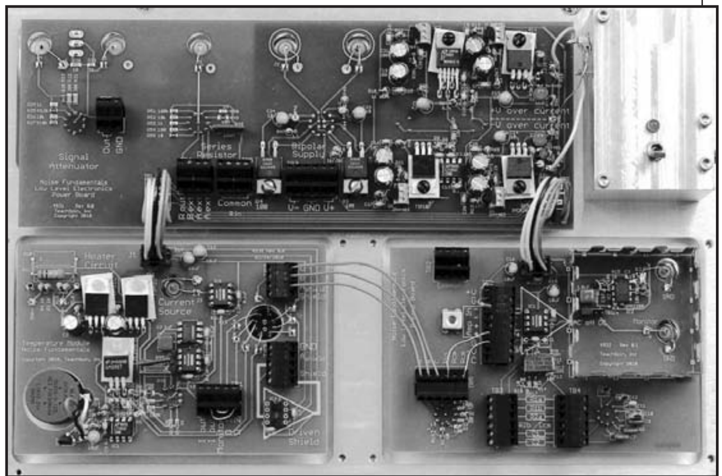


Fig. 2 Back side of low-level electronics, with panel flipped top-to-bottom so that preamplifier is on the lower right hand side.

The high-level electronics, Figure 3, consists of a series of modules. The noise signal can be passed through two filter sections. Each filter module has two-pole Butterworth response with High-pass, Band-pass and Low-pass outputs available.

Fig. 3 Control panel for high-level electronics

The corner frequencies of the first filter are switch selectable for 10, 30, 100, 300, 1 k and 3 kHz. The second filter switches are 330, 1 k, 3.3 k, 10 k, 33 k and 100 kHz. The Gain module has two x10 gain stages, selected with toggle switches, and a fine adjustment stage with switch selectable gains of 10, 15, 20, 30, 40, 50, 60, 80, 100. The next module is an analog Multiplier, which will most often be used as a squarer. The squared voltage is sent to a two-pole low-pass filter to measure the mean squared voltage of the noise signal. This signal is displayed on the analog voltmeter and on the output BNC. A BNC output on the back panel gives access to a digitally generated noise-calibration signal. This provides a way for students to test their understanding, using a known high-level *pseudo-noise* signal.

The variable temperature platform consists of a copper probe, with a diode thermometer, resistive heater, and three sample supports, suspended by a thin- wall stainless steel tube. The temperature of the samples can be varied from 77° to 373°K and controlled to ± 1°K by a combination of heater power and variable insertion of the probe into liquid nitrogen in the clear dewar.

The unit can measure Johnson noise from resistors ranging from 10 Ω to 10 MΩ and over a frequency range from 3 Hz to 100 kHz. Shot noise can be measured in currents ranging from 10 nA to 1 mA.

EXPERIMENTAL DATA

Take a careful look at some of the experimental data taken by Dr. George Herold, principle designer of the electronics for NF1-A. The caption below each figure explains the experiment performed.

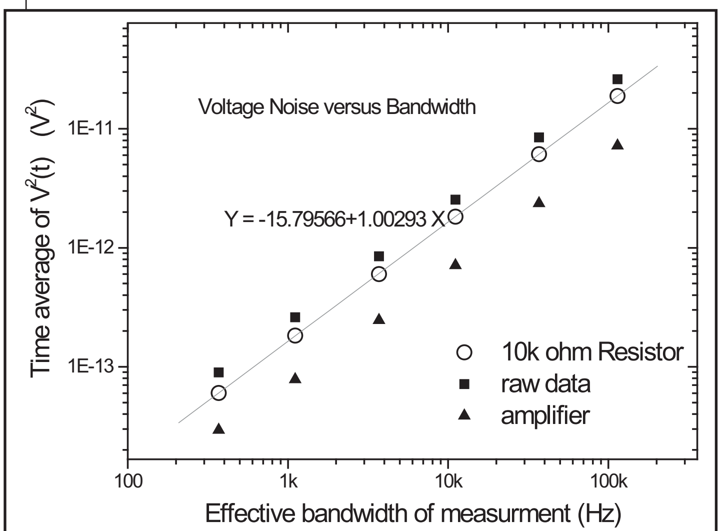


Fig. 4: Johnson noise of a 10 kΩ resistor, for a range of bandwidths, at room temperature. This log-log plot shows a linear fit with a slope of 1.003 indicating a $V^2 \sim \Delta f$ over three orders of magnitude, consistent with theoretical expectations.

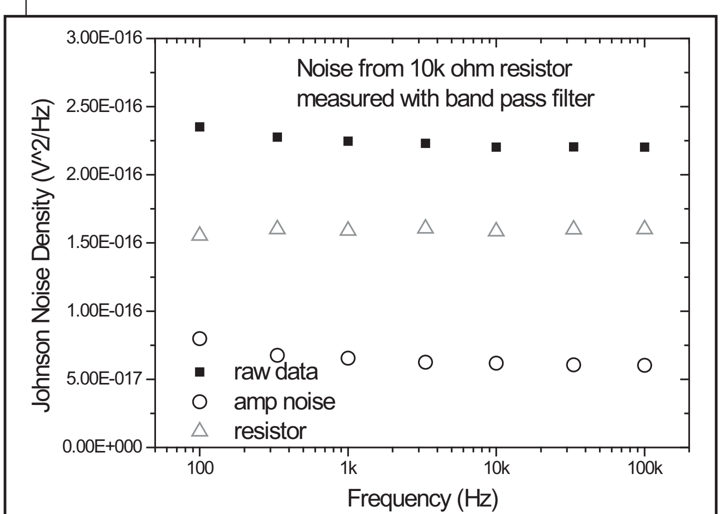


Fig. 5: Data from Fig 4 replotted in 'units of noise', $V^2/\Delta f$. We see that the noise density is 'white', that is, independent of the center frequency.

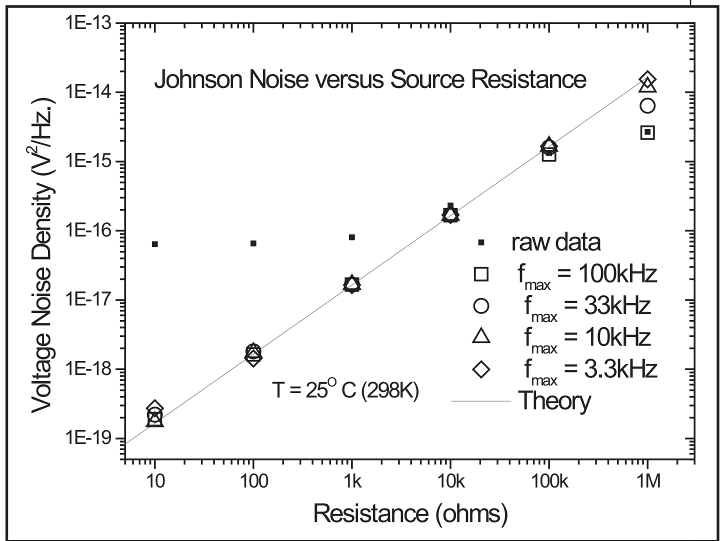


Fig. 6 A test of the claim that Johnson noise power is proportional to source resistance. Also, the measurements determine Boltzmann's constant to be $k = 1.399 \pm .028 \times 10^{-23}$ J/°K

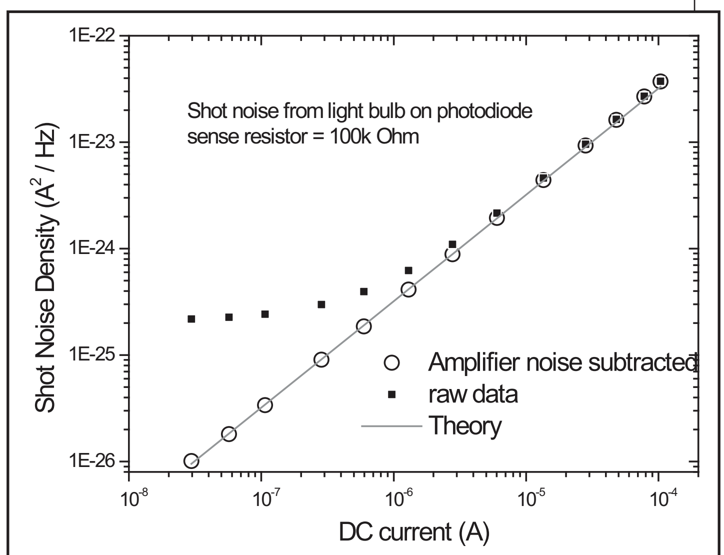


Fig. 7 Shot noise from a photodiode illuminated by a light bulb. The charge on the electron, as determined by this data, is $e = 1.593 \pm .016 \times 10^{-19}$ C

Figures 4, 5, 6, 7 are samples of some of the data that students can acquire with this apparatus. There are many other possibilities. Here is an opportunity to have your students learn fundamental physics, important electronics, and develop real experimental skills. As has been our tradition, the first units are sold at a substantial discount, so get your orders in soon. We expect to be shipping units by August 1, 2010, so that they will be available for the Fall semester.

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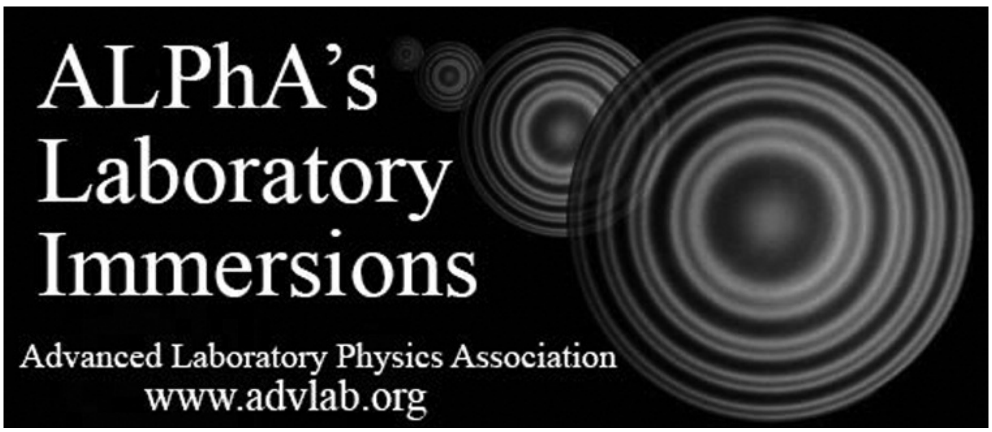

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June 17 – 18	Dickinson College: Single Photon Quantum Mechanics
July 17	AAPT Portland: LabVIEW
Aug 2 – 4	Buffalo State College: Pulsed NMR, Optical Pumping, Modern Interferometry, Mossbauer Spectroscopy, High Tc superconductivity
Aug 11 – 13	Caltech: Vacuum Techniques/Thin Film Deposition, Low-Noise Signal Detection with Lock-ins, Saturated Absorption Spectroscopy, Resonant Absorption and Refraction