Ph/EE/BE/APh 118a – Fall 2018
Physics of Measurement

Prof.: Michael Roukes, x2916, 131 Bridge Annex *(roukes@caltech.edu)*
T.A.: Raj Katti, x2684, B138 Bridge Annex *(rmkatti@caltech.edu)*
Admin.: Nancy Roth-Rappard, x2933, 127 Bridge Annex *(nrappard@caltech.edu)*

Homework Assignment #1
(Due: Thu 10 Oct 2019, *by e-mail to Raj*)

1. I am curious to know about your current measurement endeavors. This will help me tailor examples as we go forward to the interests of the class. (If you are an undergraduate, please report on a SURF or other experimental project you've done. If you don't have such experience write to Raj, and he'll suggest an example to analyze as per below.)

    a) What is/are the signal domain(s) of your experiment(s)? (If you said something generic above (like "photons" or "voltage"), please be very specific about what you are trying to extract from your signal domain measurements.)

    b) What is the expected/normal operating range of your measurements?
    What sets the noise floor for the signal itself?
    What is the largest signal level that one might anticipate? Here, consider the signal you're interested in, but also consider separately the magnitude of possible interfering signals or noise. How many dB of dynamic range are required to handle the full range expected (for everything: desired signals, interference, and noise).

    c) What is the first responsivity involved in your measurement? This is often the one that has to be optimized the most to get good system-level SNR.

    d) If that first responsivity doesn't carry you all the way to the voltage domain – what else is involved in getting there? Draw an "information flow diagram" like I presented in class. Be specific about the cascaded responsivities in your experiment(s), as in the example from *Lecture 1* concerning the magnetic force microscope.

    e) Describe the noise processes that enter your measurement for each stage of the measurement "chain".

2. Think up an independent example of a measurement system with a ganged responsivity. What are the units for each element's responsivity? What are the units for the overall system's ganged responsivity?

3. **Scenario:** An amplifier chain consists of four cascaded amplifiers, each having a voltage gain of 100 (power gain +40dB). The input amplifier has voltage noise spectral density of $(0.4nV/\sqrt{Hz})^2$.

    a. Please explain in your own words the (strange) units for voltage noise spectral density.

    b. What is the maximum square-root voltage noise spectral density (referred to its own output) that each amplifier must achieve in order to avoid increasing the TOTAL (after four amps) "cascaded-system" square-root voltage noise spectral density RTI by a factor of two? (Assume that each amplifier after the first contributes equally to the degradation of the overall system SNR.)

    c. Assume that, after the first stage, subsequent stages 2, 3, and 4 have the <u>same</u> voltage noise spectral density RTI. What is the maximum square-root voltage noise spectral density (referred to their own inputs) these amplifiers must have in order to avoid increasing the <u>total</u> "cascaded-system" square-root voltage noise spectral density RTI by a factor of two?

4. For examples 3b) and 3c) above, what percentage of the total (cascaded system) noise spectral density RTI do each of the four amplifiers contribute?