16722 homework due 2009 01 26

(8) Noise voltage expected from $100\,M\Omega$ output impedance sensor in 100 MHz bandwidth at room temperature, 30K, and 3000K?

$$|V_n| = \sqrt{4kT\,\Delta f\,R}$$

At room temperature, $\sim 300\,K$, $kT \approx \frac{1}{40}\,eV$

so $$|V_n| = \sqrt{\frac{4}{40}\,\cancel{e}V \times 100\times10^6\,\cancel{Hz} \times 100\times10^6\,\cancel{ohm} \times 1\,\frac{volt}{\cancel{ampere}\cdot\cancel{ohm}} \; 1.6\times10^{-19}\,\frac{\cancel{coulomb}}{\cancel{e}}}$$

$$= 1.3\times10^{-2}\,V$$

The other two temperatures are 0.1 and 10 times 300K, so result is smaller and larger by $\sqrt{10}$ respectively or about $(0.4 \text{ and } 4)\times10^{-2}\,V$ respectively.

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(9) What current noise magnitude would you expect to see on the highest sensitivity setting of a modern picoammeter in bandwidth 100 kHz?

Web search turns up Keithley Models 6485 & 6487 with advertised 10 fA resolution.

So let's say we are using it to measure a current around 100 fA, so in the absence of noise our measurement would have a resolution of about 10% of full scale.

The noise in BW ≈ 100 kHz is then

$\Delta I \approx \sqrt{2 \times 10^5 s^{-1} \times 1.6 \times 10^{-19} \text{coulomb} \times 100 \times 10^{-15} \text{coulomb } s^{-1}}$

$\Delta I \approx 6 \times 10^{-14} A \approx 60$ ~~pA~~ fA

So the noise is ≈ 60% of the anticipated signal!

BUT if we read further down the spec sheet (6485) we find that the 10 fA resolution is available on the 2nA range, where it says the typical RMS noise is 20 fA, 3x better than our calculation. Why? because the "rise time" on that scale is 8 mS, from which we can surmise the actual bandwidth possible corresponds to a period of about 32 mS, or a BW of about 30 Hz vs our assumed (or desired) 100 kHz. Using this BW we get $\Delta I \approx 1$ fA, so the product is ~ 20x worse than this ideal.

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(10) Browse the "$\frac{1}{f}$ noise" website, find an interesting subtopic and article, and summarize it, mentioning at least: is it theoretical / computational / experimental? what observation exhibits $1/f$ noise? How close is the exponent to 1?

I chose "$\frac{1}{f}$ noise: a pedagogical review" by E. Milotti, because after browsing the many specialized articles I found it hard to understand them because they are written for experts in the field. Even this "pedagogical" article is rough going in the mathematics, but at least the experiments described are mostly old, simple, and clearly explained. I think the most interesting example is that of Figure 8, in which fluctuations in simple electronic devices (op amps) were monitored for three months, allowing over six decades of frequency and seven decades of noise power, indicating an $f^{-1.23}$ power law. It is interesting that in his conclusion the author states that he does not believe there is any underlying universal "$\frac{1}{f}$ law", but rather just a large collection of examples that exhibit this behavior.