Outline

• Noise in circuits
  – Internal noises (produced by circuit components)
    – Johnson Noises (recap)
    – Shot Noise
    – Flicker (1/f) noise?
  – How to find the least noisy amplifier for your application?

Johnson noises?

• $V^2(f) = 4RkT$

What is Shot noises?

• When current flows, actually, individual electrons are flowing.
• Over a time of $\Delta t$, current flow of $I$ means that $N_e = I\Delta t/e$ electrons are flowing.
• Since there will be Poisson fluctuation on this number, the fluctuation in the current will be $\Delta I = \sqrt{I\Delta t/e} \times e/\Delta t = \sqrt{Ie/\Delta t}$.
• Or, $<\Delta I^2> = Ie/\Delta t \approx Ie \times \Delta f$. (note that $\Delta t \cdot \Delta f \approx 1$ is a characteristics of all sine waves.)
• In reality, there is a factor 2, so $<\Delta I^2> = 2Ie \times \Delta f$.

Flicker Noises

• Sources are still under investigation.
• Refer you to the following reviews in Reviews of Modern Physics:
• Because of 1/f frequency dependence, it’s not important at high frequencies (typically above 1 kHz).
  – This also implies that if it is possible, avoid DC or low frequency measurements.
    For light detection, for example, use a chopper to modulate the light intensity so that you don’t have to deal with DC.
• This noise is caused by fluctuation in the resistance.
• One of the speculations is that it may be caused by fluctuation in the charge carrier density in the resister.
• One of the possible models explains the charge carrier density fluctuation by trapping of electrons by some surface characteristics – does explain 1/f dependence.
• Various observations can be summarize by phenomenological formula: $S_R(f)/R^2 = \alpha_H/N_f$, where $\alpha_H \approx 2 \times 10^{-3}$ (Hooge, 1969). This gives useful “rules of thumb” estimate of this noise.
• The power of $f$ is not exactly $-1$ for most cases, and actually varies from 0.9 to 1.4.
• Inclusion of $N_c$ made it possible for this formula to describe $1/f$ noise for metals as well as semiconductors.
• Some observations with this formula:
  – $\alpha_H$ is dimensionless only when the power of $f$ is $-1$, AND the power of $R$ is also 2.
  – Inclusion of $N_c$ implies that the mechanism of this noise involves independent individual charge carriers (each carrier “creates” certain amount of noise but this view does not produce theories which are consistent with other observations).
  – Because of this $N_c$ factor, this noise is a lot more important for semiconductors.
  – $1/f$ implies that the total amount of noise is infinite! This in turn implies that this noise has a cut off at either low or high frequencies (or both, depending on if the power of $f$ is greater or smaller than $-1$) by some mechanism.
  – $S_v \approx 3 \times 10^{38} J^2(A^2cm^4) L/A(cm)$, $J$ is current density and $L$ and $A$ are the length and the cross sectional area of the resister.
  – For $R \approx 100 \Omega$, one can measure noise of $10^{-19} V^2 Hz^{-1}$, this implies that $J/L/A$ of $10^{18}$ can be detected. In turn, this implies that one has to have fairly large current density ($10^5 A cm^{-2}$) and small size ($A/L < 10^6 cm$).

SNR, NF, etc.

• What you really want is the best SNR – Signal to noise ratio, or its db version – take the log of the ratio.
• $SNR = 10 \log_{10}(V_s^2/V_n^2)$.
  – Usually, $V_n$ grows as the bandwidth of the amplifier increases, whereas $V_s$ stays the same once the bandwidth covers where the signal is. So it’s crucial that your amplifier covers only minimum necessary frequency band.
  – Bandpass filter gives you this.
• Since this figure cannot be specified for an op-amp (without knowing the signal level, $V_s$), we use NF to specify the inherent capability (figure of merit) of an amp, where the noise of the amp is compared to that of the inherent Johnson noise (at its input):
• $NF = 10 \log_{10}((V_n^2 + V_J^2)/ V_J^2)$, where $V_n$ is the noise from the amp, and $V_J$ is the Johnson noise, which is an unavoidable noise.
• NF depends on the frequency as well as the source impedance, $R_s$ (only real part counts for noise!)
  – high $R_s$ makes $V_J$ large and masks $V_n$. This is not a real improvement of your circuit even though NF will improve.
  – Note that often $V_n$ itself does depend on $R_s$.
• Usually, since you don’t have control over $R_s$, you should choose the amp with smallest NF for your $R_s$ and signal frequency.
  – Note that you could use a transformer to change $R_s$ if that really improves $V_n$.
  – Adding extra resister in series with the signal source to increase $R_s$, on the other hand, is not a good idea since it increases $V_J$ without increasing $V_s$ (often decrease it)