Problem Set 2

January 31, 2015

1

This question is based off of material from B. Boser at UC, Berkeley.

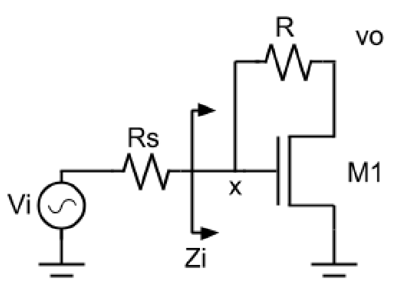
1.1

(5 points) Figure 1a represents a common type of amplifier which consists of $M1$ and R called a transimpedance amplifier. R_s in this model could represent the output of any number of sensors. Often R_s will be quite high, which means the sensor will have a great deal of voltage noise and will output very little current. Per the maximum power transfer theorem, the most power will be pulled out of the sensor when the input impedance of the sensor is the same as the source impedance: i.e. when $Z_i = R_s$.

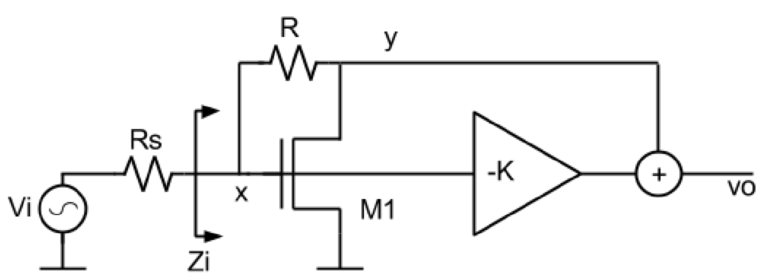
Use our standard analog model to find the following: Z_i, the relationship between g_m and R_s, the gain from v_i to v_o, and the noise factor of the circuit. Assume the system is impedance matched, R is noiseless, C_{in} is insignificant (we're going slow), r_o is large and C_d is small. Note that R_s doesn't count as "part of the amplifier" for purposes of calculating the noise factor. Instead it is considered to be input noise.

1.2

(5 points) Figure 1b, shows a modification to this amplifier. Is this a good modification? How much power is the K amplifier allowed to consume relative to the transistor in order to be considered a good power tradeoff?

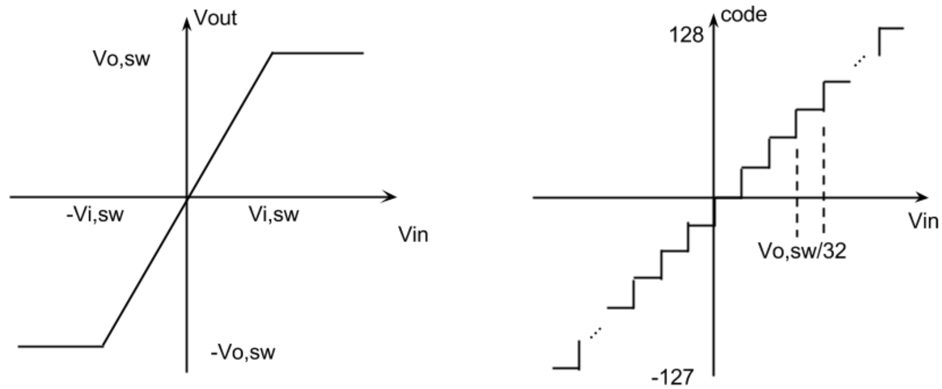


(a) Transimpedance Amplifier



(b) Modified Transimpedance Amplifier

Figure 1



(a) Amplifier Transfer Function (b) ADC Transfer Function

Figure 2: Transfer functions for dynamic range calculation

2

2.1

(1 point) Consider the composite ADC+amplifier system from problem set 1. The Figures for that problem are reprinted in Figure 2. Now that we have the machinery to include quantization noise in our calculations, recacluclate the dynamic range of the system. The amplifier still has an input referred thermal noise of $NkT\Delta f$ and a bandwidth of ω. $\sqrt{NkT\omega} = V_{i,sw}/20$ is also still true.

2.2

(1 point) Assume the amplifier + ADC system is being used to measure the potential around a shank inserted into a brain. The peaks of the voltage spikes caused by ion channels are $V_{NP} = 10\mu\text{V}$, and contain frequency components up to 10kHz. Fluctuations of other, slightly more distant, neurons causes a random, white (within the band where neuronal activity happens), background fluctuation of v_{NN}=1 µV RMS. What is the dynamic range of this signal? Report the dynamic range in both linear scale and decibels.

2.3

(8 points) Let's examine what it would take for our Amplifier+ADC system to be used as the front end of an implanted brain monitoring chip. Such a chip might be used to detect and prevent seizures, and obviously its ongoing power consumption woudl be an important consideration to avoid having to perform surgery to change the batteries.

Assume we need at least 6dB of SNR for our signal processing algorithms, and the the ADC energy/sample is 50pJ for a 100µV LSB at the frequencies we're interested in. Reducing the LSB size by half increases the ADC power by 8x and increasing the LSB size by a factor of two reduces the ADC power by 8x. Assume the neural signals are the same as the previous problem.

We are also changing the noise model we use for our amplifier in this problem. Assume the amplifier has the same noise figure as that of a common source amplifier rather than our tusty, fixed $NkT\Delta f$ of input noise. The size of our chip limits us to 10nF of capacitance, all of which are used in the amplifier. The amplifier consumes 2µW of power when operating at 10kHz with 10 nF of capacitance and a gain of 2.

How much gain should the amplifier have and what size should the ADC LSB be to minimize power? What is the bandwidth of the amplifier and the conversion rate of the ADC?