Homework Problems for Operational Amplifiers

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The following are some selected worse case specifications for some common operational amplifiers. Use this data is solving the problems below.

Op-Amp	Av	Vos	IB	IBos	Comments
LM741C	20,000	7.5 mV	800 nA	300 nA	Ancient
LM324	25,000	7 mV	250 nA	50 nA	Very popular
TL084	30,000	20 mV	10 nA	2 nA	Very popular
AD549J	80,000	2 mV	250 fA	50 fA	Premium

In describing the circuits, the following convention is used:
Rf = resistor between output and inverting input
Ri = resistor from inverting input to either ground or a signal source
Rb = resistor from non-inverting input to either ground or a signal source

For each problem, calculate the magnitude of the output voltage due to each of the error terms, Vos, IB, and IBos. Do this for each of the four op-amps listed above. Then calculate the 1-sigma range of the output voltage error by computing the square root of the sum of the squares of output voltage error for each of the three error terms. In most cases, the TL084 will have the highest 1-sigma error range and the AD549J will have the smallest. Note that the LM324 and TL084 will vary in terms of having the lower 1-sigma output error voltage. Also for each problem, calculate the ideal gain assuming infinite Av, and compare this against the actual gain using Av from above. Assume the signal source has zero DC resistance to ground.

1. Rf = 100K, Ri = 470, Rb = 0. Input source connected to non-inverting input.

2. Rf = 1M, Ri = 4.7K, Rb = 0. Input source connected to non-inverting input. Note the difference in the output voltage errors compared to problem 1.

3. Rf = 10K, Ri = 47, Rb = 0. Input source connected to non-inverting input. Note the difference in the output voltage errors compared to problem 1.

4. A current output device (such as a photomultiplier tube) is connected to the inverting input of an op-amp. Rf is 10M. Rb is 0. Ri is not used (Ri = 0) since the photomultiplier tube appears as an infinite (or at least extremely large) impedance (thus, Ri can be considered to be infinite in the usual calculations). Calculate the trans-impedance gain (delta Vo / delta Iin, note that this has units of Ohms) of the amplifier using infinite Av. Calculate the 1-sigma voltage output error band for each of the op-amps.

5. Repeat problem 4 except that this time the source is an ion collection loop (also a current source with essentially infinite source resistance), Rf is 1000M. It is desired to clearly resolve a 5 pA current from the ion loop – what output voltage

results from a 5 pA input current? Note that this problem really reveals the qualities of the AD549 op-amp which is made specially for this purpose.

6. Repeat problem 2 except first calculate the value that Rb should be to properly bias current compensate the op-amp and use that value instead of 0. Compare results with those of problem 2. Identify which of the four op-amps that the improvement of Rb was worthwhile and identify which of the four op-amps for which the improvement was of little to no consequence.

7. Consider a non-inverting amplifier with Rf = 20K, and Ri = 1K, and Rb = 0. There is a capacitor in series with Ri. The reactance of this capacitor is negligibly small at the signal frequency of interest. Calculate the AC gain of this amplifier. Prove that the DC gain is 1. Show also that the output voltage errors have only a gain of 1. Do not forget that for DC calculations that Ri is infinite due to the capacitor in series. Show that to properly bias current compensate this amplifier that Rb should equal Rf.

8. If Rf = 100K and Ri is 10 Ohms, what is the theoretical non-inverting gain of the amplifier with Av = infinity and the actual gain with Av = provided value on first page? If Rf were made ten times larger, how much would the actual gain increase? For each of the four op-amps, find the maximum actual gain that can be achieved such that the actual gain is within 1% of theoretical. Repeat for actual gain within 0.1% of theoretical.