E4215: Analog Filter Synthesis and Design
Operational amplifier: model for dc offset

Nagendra Krishnapura (nkrishnapura@mltc.com)

4 Feb. 2003

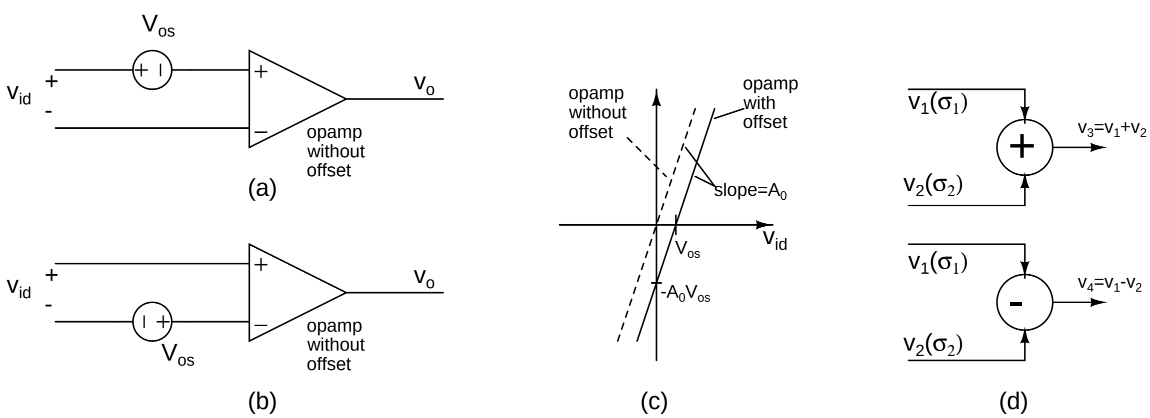

Figure 1: Modeling operational amplifier's dc offset

Fig. 1 shows the model of an opamp with dc offset. A dc voltage is used in series with one of the inputs as shown. Fig. 1(a) or Fig. 1(b) is chosen based on convenience for circuit analysis.

The offset causes the dc input output characteristic of the opamp to not pass through the origin. Fig. 1(c) shows the input-output dc characteristics of an opamp with a gain A_0 with and without offset. As seen from Fig. 1(c), the input referred offset[1] is V_{os} and the value of the output offset[2] is $-A_0 V_{os}$. The output offset is undefined when $A_0 = \infty$. An opamp's offset is always specified as an input referred offset.

The primary effect of the offset of an opamp is to cause an offset in the circuit built using the opamp. The offset of circuit can be specified as an input referred offset or an output offset. The output offset of the circuit using an opamp is the output voltage of the circuit with the input set to zero and the offset source V_{os} active.

The offset V_{os} is a random quantity that varies from one opamp to another. It usually has a Gaussian[3] distribution and is specified by its standard deviation σ ($\sigma \geq 0$ always).

[1] x intercept: The value of v_{id} required to obtain a zero output v_o.

[2] y intercept: The value of output v_o with input v_{id} set to zero.

[3] For our purposes, this means that if an opamp's offset if specified as σ mV, 99.99% of the samples of that particular opamp will have offset voltages $-3\sigma\,\text{mV} \leq V_{os} \leq 3\sigma\,\text{mV}$.

To analyze the offset of a circuit using an opamp with an offset V_{os}, determine the output voltage of the circuit with the input set to zero and the offset source V_{os} active. If the output voltage v_{out} of the circuit turns out to be kV_{os}, its standard deviation is $|k|\sigma$. The circuit is said to have an output offset voltage with a standard deviation $|k|\sigma$.

With multiple offset sources (as would be the case in a circuit with more than one opamp), the circuit has multiple random sources, uncorrelated from each other. The analysis is done with one offset source active at a time and all other offset sources set to zero. The resulting output offsets are added in a mean squared sense to obtain the net output offset.

For example, if v_1 and v_2 were *uncorrelated* random voltages in Fig. 1(d) with respective standard deviations σ_1 and σ_2, the sum v_3 has a standard deviation $\sqrt{\sigma_1^2 + \sigma_2^2}$. The difference v_4 has exactly the same standard deviation. In general if N *uncorrelated* voltages $v_1, v_2, \ldots, v_N$ with standard deviations $\sigma_1, \sigma_2, \ldots, \sigma_N$ are added together, the standard deviation of the sum $\sum_{k=1}^{N} v_k$ is $\sqrt{\sum_{k=1}^{N} \sigma_k^2}$.

The "opamp without offset" in Fig. 1 can be modeled in any of the numerous ways discussed in class (ideal infinite gain, First order model etc.). Note that this is the "dc" offset, i.e. has a zero frequency. When a frequency dependent model is specified for the opamp, or when the circuit has other frequency dependent components, the circuit can be simplified to its dc picture[4] for dc offset analysis.

[4]capacitors open; inductors shorted; Any frequency dependent function $F(s)$ substituted by $F(0)$.