CMOS Operational Amplifier

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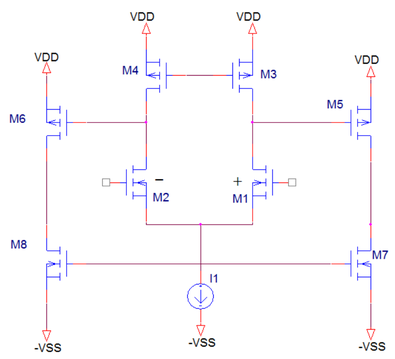
Background

An operational amplifier (op-amp) is a voltage amplifier with a differential input and a single-ended output. Op amps are important building blocks for a wide range of electronic circuits. They are among the most widely used electronic devices today, being used in a large array of consumer, industrial, and scientific devices. They may be packaged as components, or used as elements in complex integrated circuits.

Operational Amplifier Architecture

The op amp is designed using CMOS technology. P-MOSFETs and N-MOSFETs are the type of transistors that make up CMOS technology. The basic architecture stems from a differential pair and utilizes two stages to increase gain, input resistance and output voltage swing.



Two stage differential pair architecture

Design Techniques

To maintain proper operation of the amplifier some standardized design techniques were implemented.

Frequency Compensation

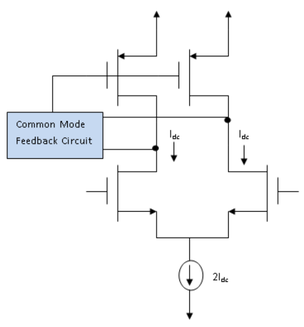
Frequency compensation was used to negate the effect of a positive zero and control the phase margin. The capacitor and resistor were added around M7 in in the circuit above.

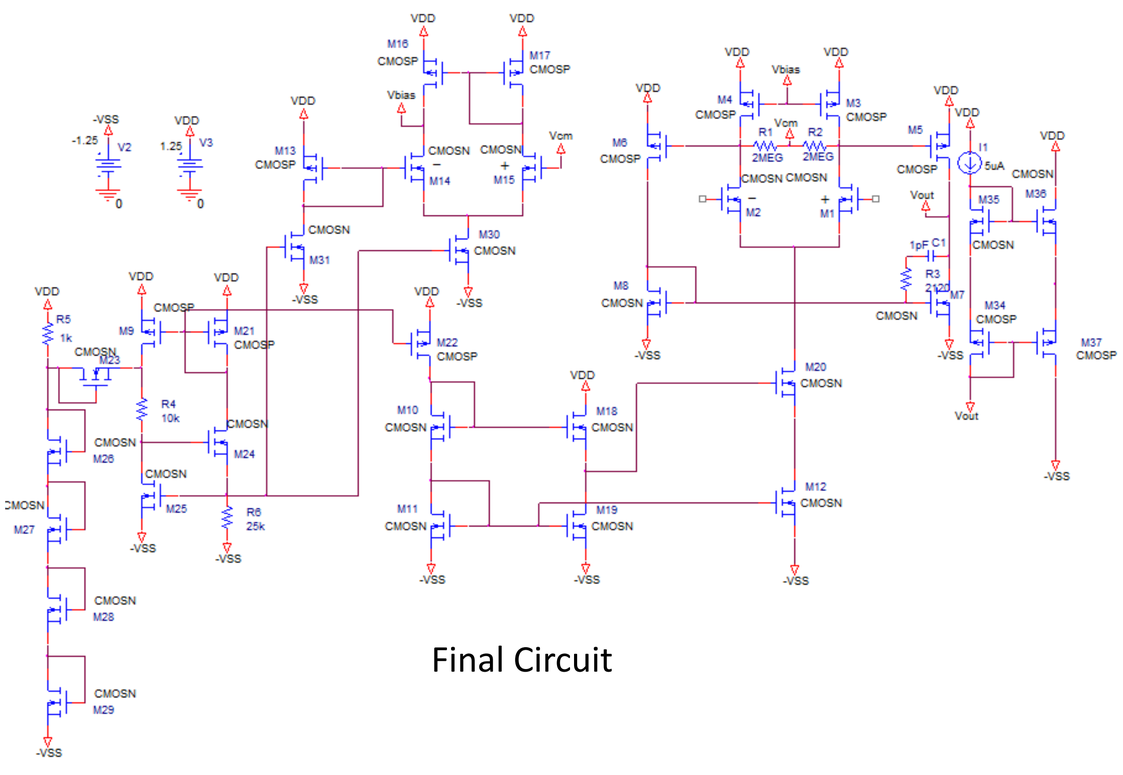
$$z = \frac{1}{\left(\frac{1}{gm} - R\right)C}$$

Setting R is equal to the inverse of the transconductance of M7 the zero goes to infinity and keeping the amplifier stable.

Common Mode Feedback (CMF)

CMF is a negative feedback loop to control the output operating point of the first stage. The CMF is looped with the transistors from the input stage. The loop takes the output of the first stage and uses a feedback circuit to bias the gate of the current load.

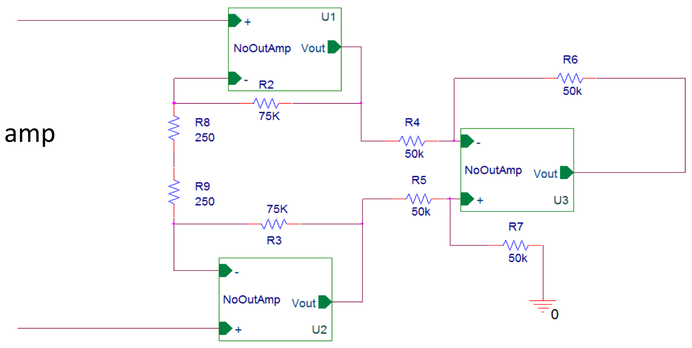




Final Circuit

Test Circuit: Instrumentation Amplifier

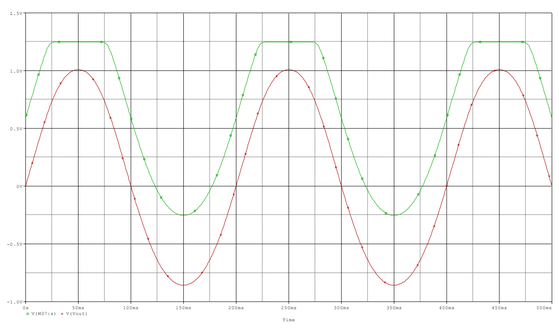
It is important that an amplifier can be used to build other electronic devices . The circuit below is an instrumentation amplifier and all results from the design is compared with an industry standard instrumentation amplifier AD620.



Circuit for testing the op amp design

Low Offset Voltage

Offset Voltage is the inherent mismatches between the threshold voltages of the MOSFETs. For the design, the offset voltage is 310 µV and the AD620 offset voltage is 50 µV.



Green Line uncorrected offset voltage
Red line is corrected offset voltage

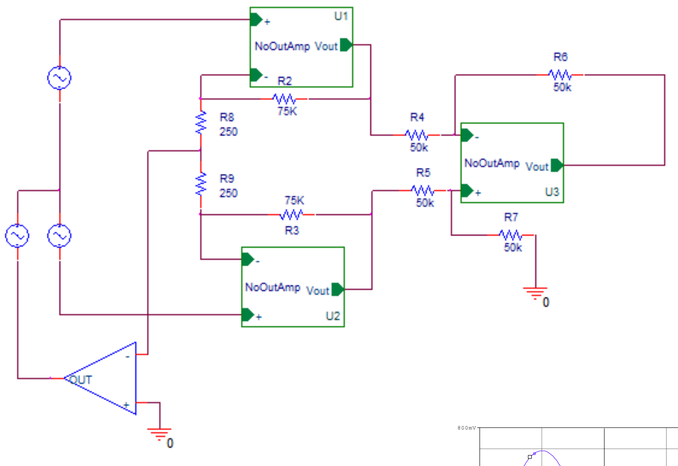
High CMRR

Common Mode Rejection Ration (CMRR) is the ability to reject the signals common to both terminals. Very important when a high common mode is present with low differential signal. The CMRR of the design is 122 dB. The AD620 can range from 110 dB – 130 dB.

Noise Analysis

Noise is a random process and an unwanted signal that degrades the integrity of information contained in a desired signal. Two categories of noise are interference and inherent noise. The input voltage noise is 4.8 µV/(Hz)^1/2. The AD620 amplifier is 9nV/(Hz)^1/2 .

Cardiac Signal Example



Implementation of a simulated cardiac signal from a human body

Output signal from the test circuit