EE 508

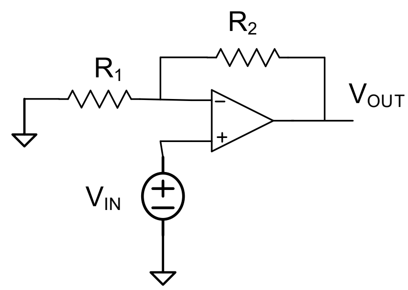
Switched Capacitor Amplifiers and Noise

Lab 6 Fall 2022

Noise

Noise is often of concern in amplifier and filter structures. In this part of this experiment, emphasis will be placed only on observing the noise that is present in an amplifier.

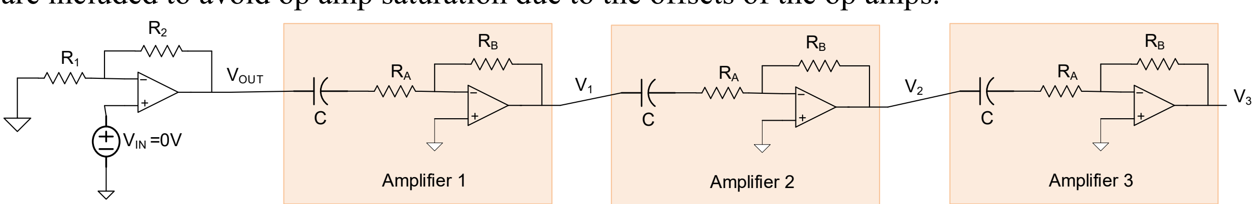
Consider the basic amplifier circuit shown below. Assuming the V_{IN} is ideal and has zero source impedance, there are three contributors to device noise in this circuit. These are the two resistors and the operational amplifier. The contribution to these noise sources all combine and appear at the output along with the amplifier version of V_{IN}. If the magnitude of V_{IN} is large, the noise on the output is often of little concern but if V_{IN} is small, the noise may be comparable in amplitude or even bigger than the output due to the desired excitation.



Basic Amplifier Structure

Design this amplifier with a dc gain of 100 using R_2=100K and R_1=1K. Use +/- 15V biases for the op amp. If the input signal is a sinusoidal signal of 200mV p-p at 1KHz, observe the output waveform and the output noise on an oscilloscope. Analytically calculate the signal to noise ratio at the output assuming the Op Amp is noiseless.

Now we will measure the noise present in this amplifier. Consider the following circuit. The three amplifier gain stages are for the purpose of amplifying the noise on the first stage. Assume R_B=500K, R_A=5K and C=1uF. The input is set to 0V (shorted out) to amplify the noise voltage of the first stage. Again, use +/- 15V biases for the amplifier. The coupling capacitors are included to avoid op amp saturation due to the offsets of the op amps.



Observe the output waveforms of the amplifier and comment on the amount of noise present in the first amplifier stage. When making an assessment, comment on why the noise contributed by the resistors RA and RB do not significantly compromise the noise measurement of the first stage. The noise you measure will be not the total noise present on the input stage but only the noise over a certain frequency band. Comment on what frequency band of noise is present.

Switched Capacitor Circuits

Capacitor ratios can be very accurately controlled in an integrated circuit with the right sizing and layout strategies and thus they offer potential for making precision amplifiers. The good matching properties also is attractive for building filters. In this experiment, the performance of three different basic amplifier structures will be investigated. One is the basic resistive feedback amplifier, one is a basic capacitive feedback amplifier, and one is a switched capacitor.

Basic Resistive Feedback Amplifier

A basic resistive feedback inverting amplifier is shown in Fig. 1. If the operational amplifier is ideal, the voltage gain is given by the expression

$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}. \qquad (1)$$

If a practical operational amplifier is used, the finite GB of the op amp, the slew rate of the op amp, and the output saturation voltage of the op amp will limit performance.

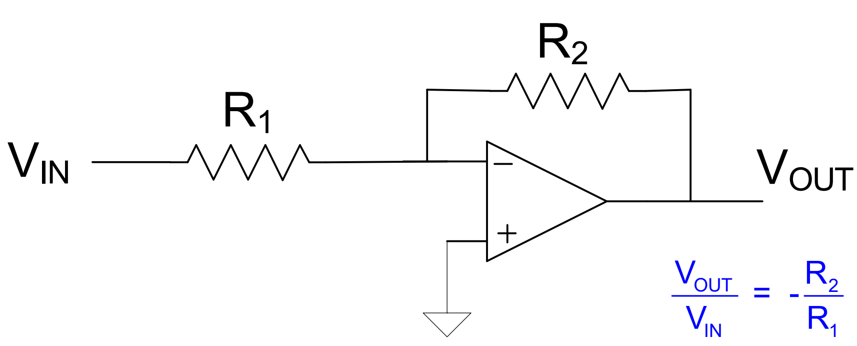


Fig. 1 Basic resistive feedback inverting amplifier

Basic Capacitive Feedback Amplifier

The most natural structure for a capacitor-based feedback amplifier is shown in Fig. 1 where, if the op amp is ideal, the gain of the circuit is

$$A_V = \frac{V_{OUT}}{V_{IN}} = -\frac{C_1}{C_F} \qquad (2)$$

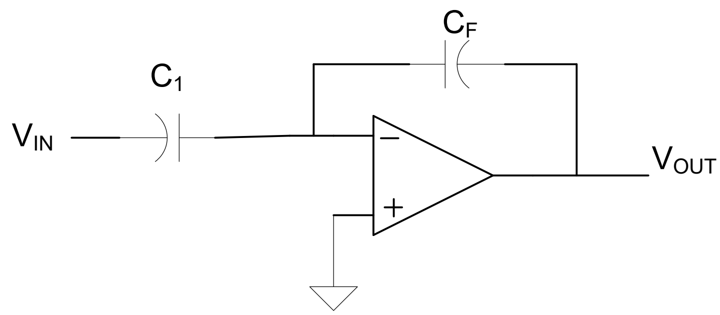


Figure 2 Voltage Amplifier with Capacitive Beta Feedback Network

It is argued that since the capacitor ratio can be very accurately controlled, the gain of this amplifier can be very accurately controlled. Unfortunately, this circuit does not perform as desired. Invariably there will be a small bias current drawn from the input terminals of the Op Amp. This bias current will cause charge to accumulate on the node connecting C_1 and C_F and this accumulation of charge will eventually (maybe after a few msec) cause the output of the op amp to saturate even if the capacitors were initially uncharged when power was applied to the circuit.

Switched Capacitor Amplifier

A variant of this amplifier is shown in Fig. 3. This is termed a charge-redistribution amplifier or a switched-capacitor amplifier. The switches are controlled by ϕ_1 and ϕ_2 which are complimentary nonoverlapping clock signals. If a sinusoidal input is applied, the frequency of the two clock signals is usually much larger than the frequency of the input. The relationship between the period of the clock signals, T, and the input frequency is shown in Fig. 4. The nonoverlap of the clock signals themselves is shown in Fig. 5. In this amplifier, the feedback capacitor is discharged during phase ϕ_1 and charge proportional to V_{IN} is stored on C_1. A the end of phase ϕ_1 this charge is sampled onto C_1. At the start of phase ϕ_2 this charge is transferred to C_F and the output voltage becomes

$$V_{OUT} = -\frac{C_1}{C_F} V_{IN} \qquad (2)$$

Thus during phase ϕ_2 the output signal is an amplified version of the input signal with gain equal to $A_V = -\frac{C_1}{C_F}$. The output signal is, however, valid only during phase ϕ_2. The fact that the output is valid only during phase ϕ_2 is not a major limitation and the gain can be accurately controlled with the capacitor ratio.

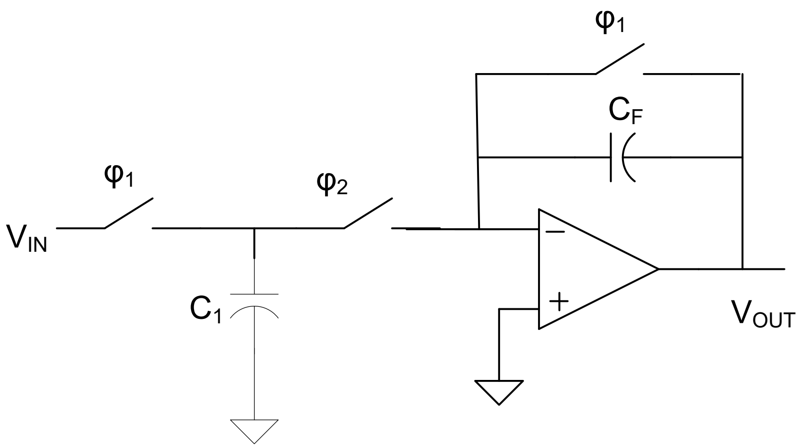


Figure 3 Basic Switched Capacitor Amplifier

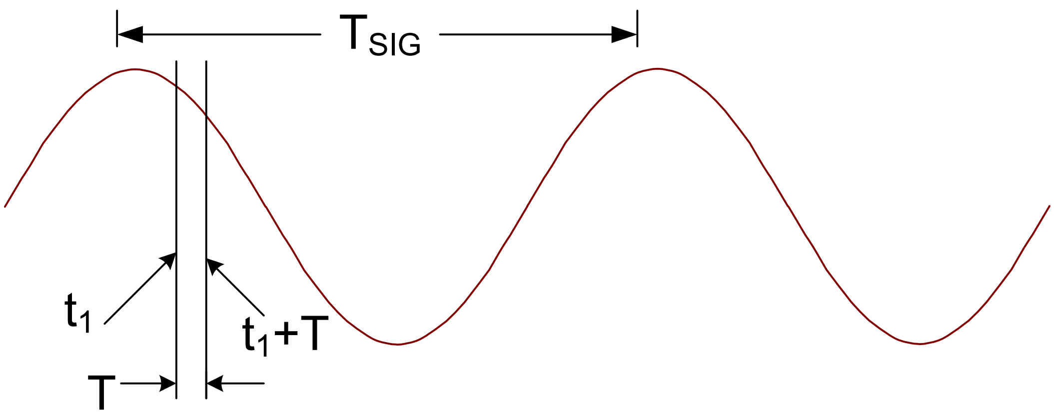


Figure 4 Timing of Switched Capacitor Clock and Input Signals

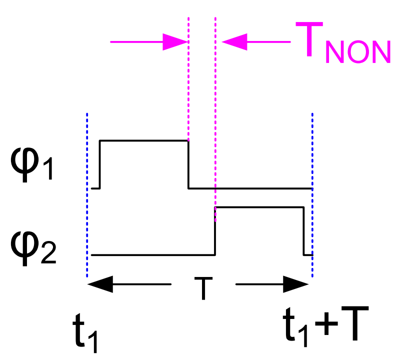


Figure 5 Non-overlapping Complimentary Clock Signals

Laboratory Procedure

Compare the performance of the three amplifiers as affected by the GB, SR, Output Saturation, and Input Bias Current of the three different finite gain amplifier structures. When considering the switched-capacitor amplifier, assume the clock frequency is 20 times the frequency of the input signal. You may assume that the input signal that is to be amplifiers is a sinusoidal signal. I will leave it to you to decide how to make the comparison but one specific metric that is of concern is the closed-loop 3dB bandwidth. To make a fair comparison, you may use the same operational amplifier for all 3 structures. Pick a commercial operational amplifier and use the model for that amplifier provided by the manufacturer. Be sure the model includes the effects that you need to consider. In this comparison, include experimental measurements for all 3 structures.

When building the SC amplifier, remember that complimentary nonoverlapping clocks are critical so a non-overlapping clock generator should be built. Use the 4066 analog switch array for the switches.