GH raisoni COLLEGE | Engineering and Management Nagpur

raisoni EDUCATION



G H Raisoni College of Engineering & Management, Nagpur

Course: Analog Integrated Circuits

Advanced Topic: Op Amp applications

Presentation By
Dr.Swati Dixit

Agenda

- Precision Voltage to Current Converter
- Active Voltage to Current Converter
- Precision Current to Voltage Converter
- Precision Current Mirror
- Simulated Inductor
- Negative Impedance Converter
- Capacitance Multiplier

Precision Voltage to Current Converter:

The very high forward gain (A_{VOL}) and differential input nature of the operational amplifier can be used to create a nearly ideal voltage controlled current source or V-to-I converter. Note in figure 1, the input voltage to be converted is applied to the non-inverting input terminal of the op amp. The inverting input terminal is connected in feedback to one end of the resistor R_1 and the source of transistor M_1. The output of the op-amp drives the Gate of the transistor. The high open loop gain of the amplifier will force the Gate of M_1 to the required voltage such that V_{IN} appears across R_1. The current in R_1 will thus be V_{IN}/R_1 and will flow only in the Source of M_1 and also thus appear in the Drain of M_1as I_{OUT}.

This configuration is also often referred to as an Active Cascode.

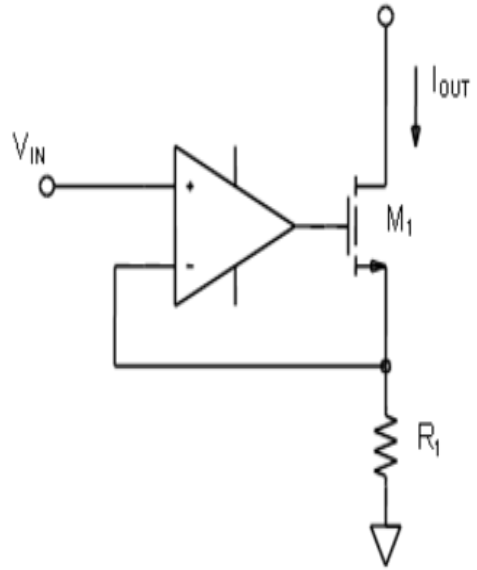


Figure 1 Precision Voltage to Current converter

Active Voltage to Current Converter:

Figure 2 shows a classic voltage to current (V-to-I) converter. The resistor values can be selected such that the output current in the load, varies only with the input voltage, V_{IN}, and is independent of the load. The circuit is widely used in industrial instruments for supplying a 4 to 20 mA signal for example. Also often referred to as a Howland current pump this configuration has two advantages over the MOSFET based circuit shown in figure 4.1. The first is a high output impedance and the second is the ability to provide bipolar (both sourcing and sinking) output currents.

The circuit has its limitations due in part to the requirement that the resistor ratios must be quite accurate to obtain a near ideal current source. Published literature describing the circuit provides design methods that are for special cases or are for approximate designs. In this chapter we explore simple design formulas that can be used to determine the component values that produce a near ideal current source. These formulas also provide a general method for calculating the output current, I_{LOAD}, for any selection of resistor values, not just the constant-current selection. Usually in order to improve stability, the circuit is made symmetrical. Therefore $R_1 = R_3$, $R_2 = R_4$, and $R_S = R_{S'}$.

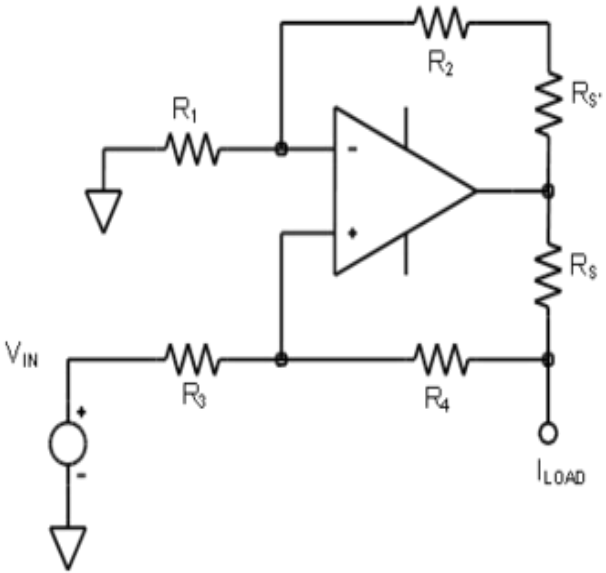


Figure 2 non-inverting voltage to current converter

For a true current output, I_{LOAD}, as a function of the input voltage, V_{IN}, you must satisfy the following equations:

$$R_1 = R_3 \ , \ R_2 = R_4 \ , \ R_S = R_{S'}$$

The load current is:

$$I_{LOAD} = \frac{V_{IN}}{R_S}\left(\frac{R_2 + R_S}{R_1}\right)$$ .....Equation 1

The Output impedance is:

$$Z_{OUT} = \frac{R_3 R_{S'}(R_1 + R_2)}{R_1(R_4 + R_S) - R_3(R_2 + R_{S'})}$$ .....Equation 2

Precision Current to Voltage Converter

A simple single resistor can be used to convert a current into a voltage but the voltage cannot be used directly to drive other parts of a system without potentially disturbing or altering the voltage. Often a buffer amplifier is required or the voltage may need to be shifter or “referred” to a different node (supply voltage or ground) in the circuit. Op amp circuits like those in figure 3 can perform this function.

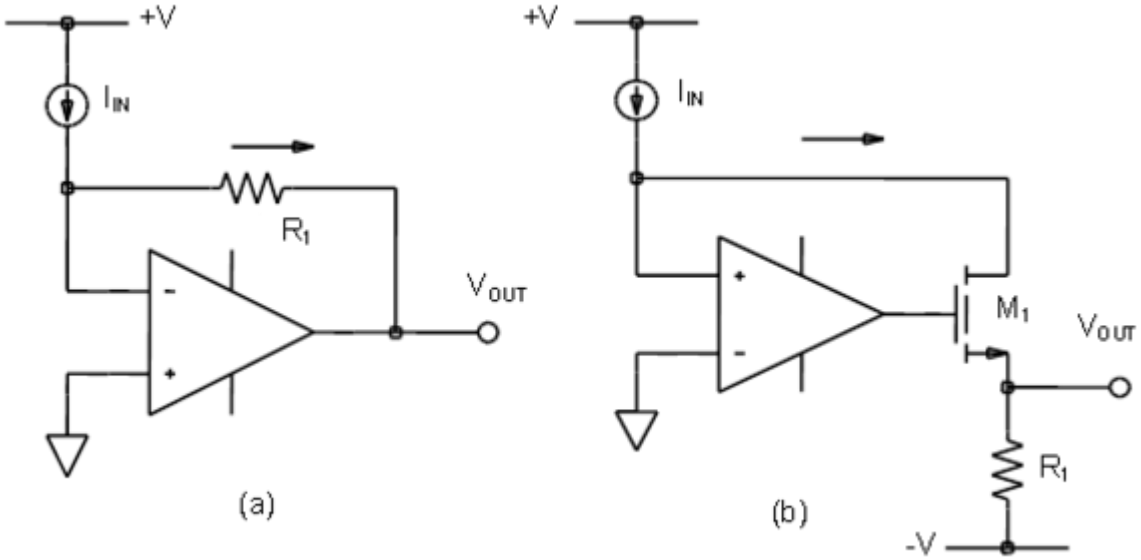


Figure 3 Precision Current to Voltage converter

Two configurations are shown in figure 3. Version (a) produces an output voltage V_{OUT} from input current I_{IN}. The output voltage is produced with respect to ground due to the virtual ground at the - input terminal of the amplifier and is negative ($V_{OUT} = -I_{IN}R_1$) for currents flowing into the virtual ground (from the +V as shown) and positive for currents flowing out of the virtual ground (flowing toward -V). Version (b) produces an output voltage V_{OUT} from input current I_{IN} as well but now it is produced with respect to some negative node potential, -V. Unlike version (a) which accepts both sourcing and sinking currents, version (b) will only operate for currents flowing into the virtual ground at the - input terminal. There is an advantage to using a MOSFET, M_1, over a bipolar transistor. In the MOSFET all the current in the drain also flows in the source (no current in gate) whereas in the case of a BJT the emitter current is increased due to the base current. The current in R_1 will thus be slightly larger than I_{IN} and the voltage V_{OUT} will not be exactly equal to $I_{IN}*R_1$.

Precision Current Mirror

We introduce the op amp in the feedback loop of the diode connected transistor. The very large gain of the amplifier greatly reduced many of the sources of error found in the simple two transistor current mirror.

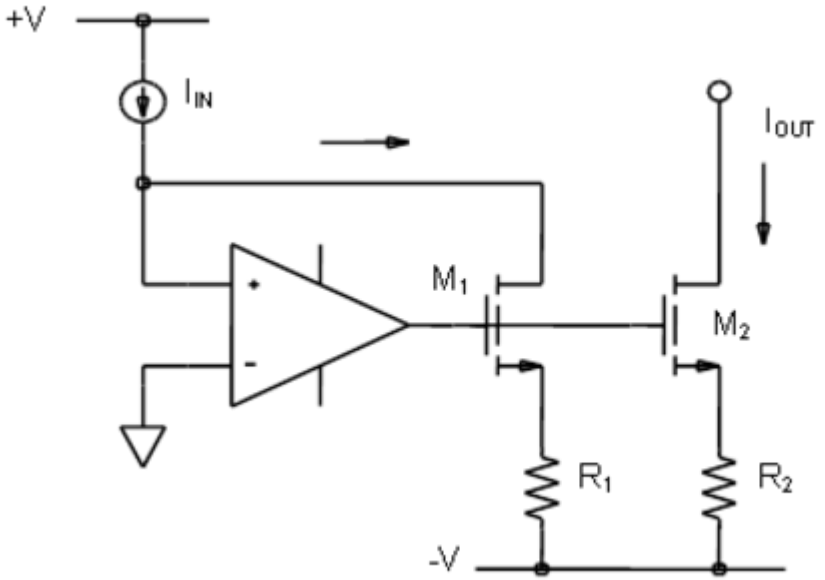


Figure 4 Precision Current Mirror

The two MOSFETs M_1 and M_2 must be well matched (and be at the same temperature) as well as the two resistors R_1 and R_2 if I_{OUT} is to be well matched to I_{IN}. If two bipolar (NPN) transistors were to be used in this case, the op amp will supply all the base current for the two transistors and providing the a and V_{BE} (I_S actually) of the two devices is well matched (and R_1 and R_2 of course) the gain of the mirror will be nearly exactly 1 in spite of the finite ß. It is also important to note that the feedback current from the drain of M_1 is to the + input terminal of the op amp. This is because of the phase inversion of the common source configuration of M_1.

Simulated Inductor

Before the introduction of the transistor and the integrated circuit, coils of wire with large inductance were used in electronic filters. An inductor can be replaced by a much smaller assembly consisting of a capacitor, operational amplifiers or transistors, and resistors. This is especially useful in integrated circuit technology where building inductors from large loops of wire is impractical.

The circuit in Figure 5 reverses the operation of a capacitor, thus making a simulated inductor. An inductor resists any change in its current, so when a dc voltage is applied to an inductance, the current rises slowly, and the voltage falls as the external resistance becomes more significant.

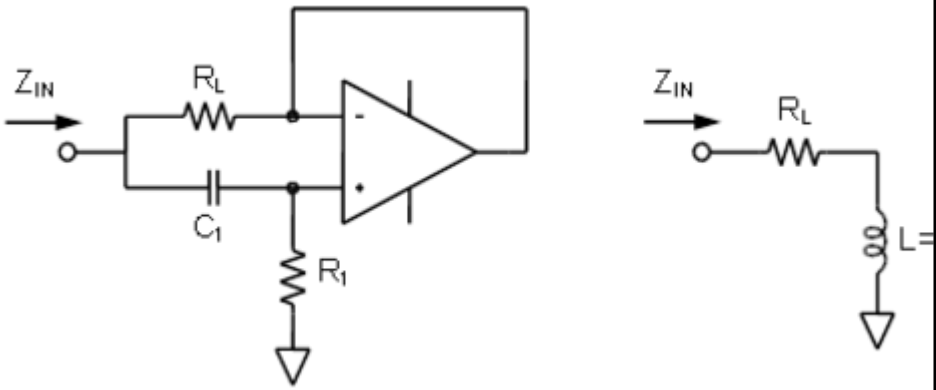


Figure 5. Simulated Inductor Circuit

An inductor passes low frequencies more readily than high frequencies, the opposite of a capacitor. An ideal inductor has zero resistance. It passes dc without limitation, but it has infinite impedance at infinite frequency.

For the circuit in figure 5, if a DC voltage step is suddenly applied to the inverting input through resistor R_L, the op amp ignores the sudden step because the change is also coupled directly to the non-inverting input via C_1. The op amp represents high impedance, just as an inductor does. As C_1 charges through R_1, the voltage across R_1falls, so the op-amp draws current from the input through R_L. This continues as the capacitor charges, and eventually the op-amp has an input and output close to virtual ground because the lower end of R_1 is connected to ground.

When C_1 is fully charged, resistor R_L limits the current flow, and this appears as a series resistance within the simulated inductor. This series resistance limits the Q of the inductor. Real inductors generally have much less resistance than the simulated variety.

There are some limitations of a simulated inductor like this:

- One end of the inductor is connected to virtual ground.
- The simulated inductor cannot be made with high Q, due to the series resistor R_L.
- It does not have the same energy storage as a real inductor. The collapse of the magnetic field in a real inductor causes large voltage spikes of opposite polarity. The simulated inductor is limited to the voltage swing of the op amp, so the flyback pulse is limited to the voltage swing.

Negative impedance converter

The negative impedance converter (NIC) is an op-amp circuit which acts as a negative load. This is achieved by introducing a phase shift of 180° (inversion) between the voltage and the current for a signal source. There are two versions of this circuit - with voltage inversion (VNIC) and with current inversion (INIC). The basic circuit of an INIC and its analysis is shown figure 6.

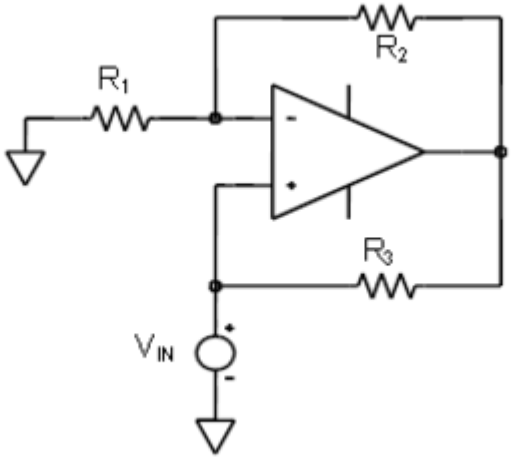


Figure 6 Negative impedance converter.

INIC is a non-inverting amplifier (the op-amp and the voltage divider R_1, R_2 in figure 4.7) with a resistor (R_3) connected between its output and input. The op-amp output voltage is

$$V_{opamp} = V_{in}\left(1 + \frac{R_2}{R_1}\right)$$

The current going from the operational amplifier output through resistor R_3 toward the source Vin is -Is, and

$$-I_{in} = \frac{V_{opamp} - V_{in}}{R_3} = V_{in} \frac{\frac{R_2}{R_1}}{R_3}$$

So the input V_{in} experiences an opposing current - I_{in} that is proportional to V_{in}, and the circuit acts like a resistor with negative resistance

$$R_{in} \overset{\Delta}{=} \frac{V_{in}}{I_{in}} = -R_3 \frac{R_1}{R_2}$$

In general, elements R_1, R_2, and R_3 need not be pure resistances (i.e., they may be capacitors, inductors, or impedance networks).

Capacitance Multiplier

The circuit in figure 7(a) uses an op-amp and a small capacitor, C_1, to simulate a much larger capacitor. It simulates the simple RC circuit of figure 7(b); the resistor $R_2$is the same size as the resistor in the circuit being simulated (R_3), but the capacitor C_1 is N times smaller than C_2.

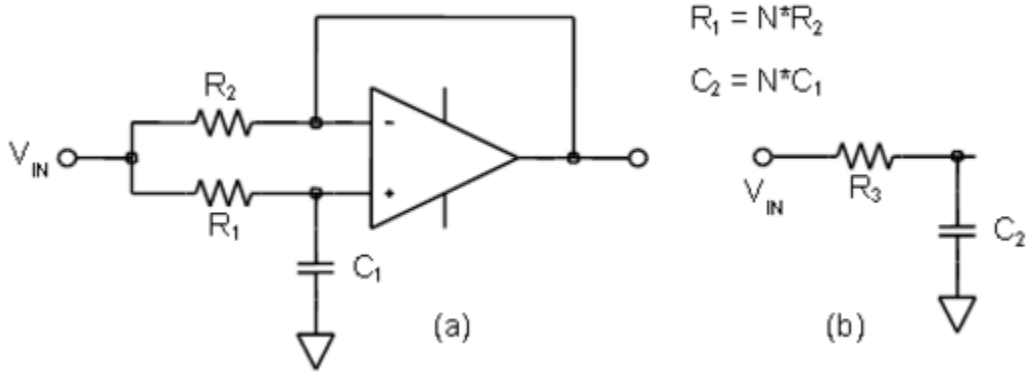


Figure 7 Op-amp capacitance multiplier

Current flows from the input source through R_1 to the capacitor (C_1). If R_1, for example, is 100 times larger than R_2, there is 1/100th the current through it into the capacitor. For a given input voltage, the rate of change in voltage in $C_1$is the same as in the equivalent C_2in figure 4.8(b), but C_2 appears to have 100 times the capacitance to make up for 1/100th the current.

The voltages across the two capacitors are the same, but the currents are not. The op-amp causes the negative input to be held at the same voltage as the voltage across C_1. This means R_2 has the same voltage across it as R_3, and therefore the same current. Since the total current from V_{IN} is the sum of the current in R_1 and R_2 and R_2 is N times smaller than R_1 the apparent charging current is N+1 times larger than the current in C_1.

Thank You