EE 321 Analog Electronics, Fall 2011
Homework #3 solution

2.73.

(a) Consider the instrumentation amplifier circuit of Fig. 2.20(a). If the op amps are ideal except that their outputs saturate at $\pm 14\,\mathrm{V}$ in the manner shown in Fig. 1.13, find the maximum allowed input common-mode signal for the case $R_1 = 1\,\mathrm{k\Omega}$ and $R_2 = 100\,\mathrm{k\Omega}$.

(b) Repeat (a) for the circuit in Fig. 2.20(b), and comment on the difference between the two circuits.

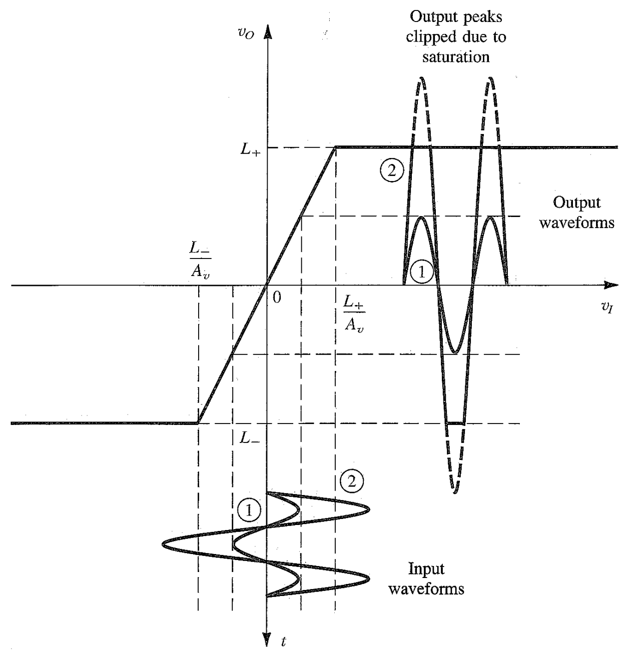

FIGURE 1.13 An amplifier transfer characteristic that is linear except for output saturation.

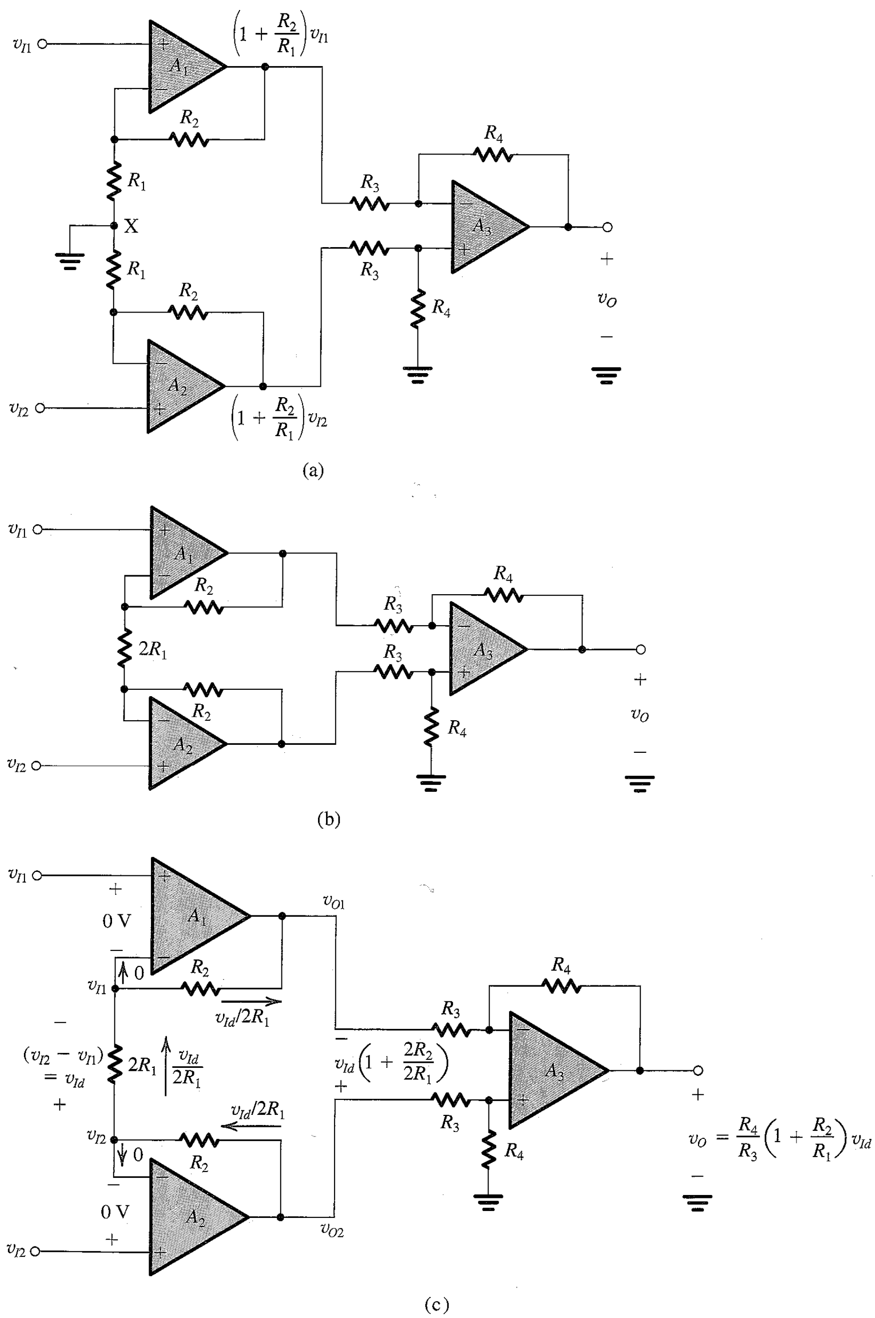

FIGURE 2.20 A popular circuit for an instrumentation amplifier: **(a)** Initial approach to the circuit; **(b)** The circuit in **(a)** with the connection between node X and ground removed and the two resistors R_1 and R_1 lumped together. This simple wiring change dramatically improves performance; **(c)** Analysis of the circuit in‘ **(b)** assuming ideal op amps.

(a) The first stage of the amplifier has a gain of 101 for both common mode and differential mode. The maximum common-mode input is thus the saturation levels divided by the gain,

$$v_{ic,\max} = \frac{14}{101} = 0.139\,\text{V}$$

(b) In this case the common mode gain is unity, whereas the differential mode gain is

101. The maximum common-mode input is again the satraution levels divided by the common-mode gain,

$$v_{ic,\max} = \frac{14}{1} = 14\,\mathrm{V}$$

The second version of the amplifier, which is the one named the instrumentation amplifier, is the better one to use as it greatly increases the allowable common-mode range on the input.

2.76. Design the instrumentation amplifier circuit of Fig. 2.20(b) to realize a differential gain, variable in the range 1 to 100, utilizing a 100 kΩ pot as variable resistor. (Hint: Design the second stage for a gain of 0.5)

We can design the second stage for a gain of 0.5 by choosing $R_4 = R_3/2$, for example $R_4 = 10\,\mathrm{k\Omega}$ and $R_3 = 20\,\mathrm{k\Omega}$.

For the first stage, we insert the pot in the $2R_1$ spot. However if we have just the pot then the gain will be infinite when we turn the pot down to zero resistance. So we must add a series resistor, so that $2R_1 = R_A + R_P$, where R_P is the pot. The first stage gain is now

$$G = \frac{2R_2}{2R_1} + 1 = \frac{2R_2}{R_A + R_P} + 1$$

We have to solve for R_A and R_2. Notice that the gain is smallest when the pot is at the largest resistance and the gain is largest when the pot is at the zero resistance. We want a first-stage gain of 2 to 200. Thus

$$G = \begin{cases} 2 & R_P = 100\,\mathrm{k\Omega} \\ 200 & R_P = 0\,\mathrm{k\Omega} \end{cases}$$

which can be written as

$$2 = \frac{2R_2}{R_A + R_P} + 1 \qquad\qquad 200 = \frac{2R_2}{R_A} + 1$$

From the second equation we get $2R_2 = 199\,R_A$. Insert that in the first equation and we get

$$2 = \frac{199\,R_A}{R_A + R_p} + 1$$

$$R_A + R_p = 198\,R_A$$

$$R_A = \frac{1}{198} R_p = \frac{100}{198} = 505.1\,\Omega$$

Then we get

$$R_2 = \frac{199}{2} R_A = 50.3\,\mathrm{k\Omega}$$