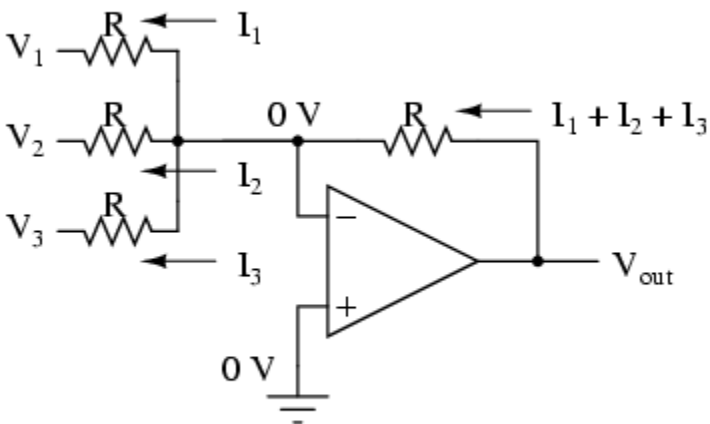


# The R 2nR DAC

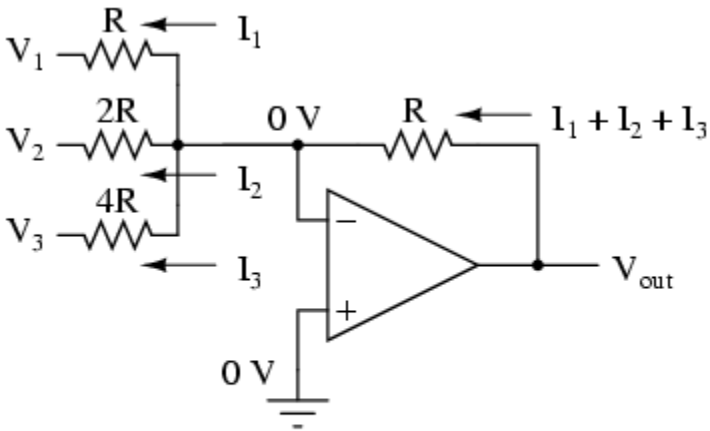
This DAC circuit, otherwise known as the *binary-weighted-input DAC*, is a variation on the inverting summer op-amp circuit. If you recall, the classic inverting summer circuit is an operational amplifier using negative feedback for controlled gain, with several voltage inputs and one voltage output. The output voltage is the inverted (opposite polarity) sum of all input voltages:

*Inverting summer circuit*



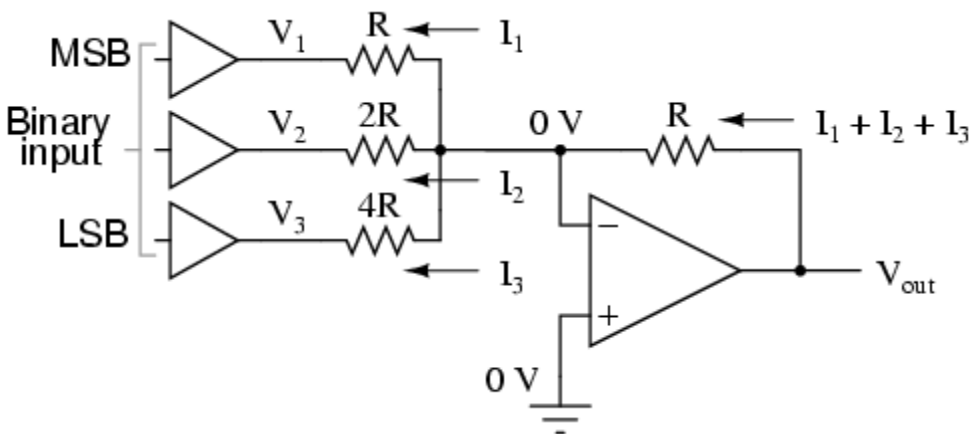
$$V_{\text{out}} = - (V_1 + V_2 + V_3)$$

For a simple inverting summer circuit, all resistors must be of equal value. If any of the input resistors were different, the input voltages would have different degrees of effect on the output, and the output voltage would not be a true sum. Let's consider, however, intentionally setting the input resistors at different values. Suppose we were to set the input resistor values at multiple powers of two: R, 2R, and 4R, instead of all the same value R:



$$V_{\text{out}} = - \left( V_1 + \frac{V_2}{2} + \frac{V_3}{4} \right)$$

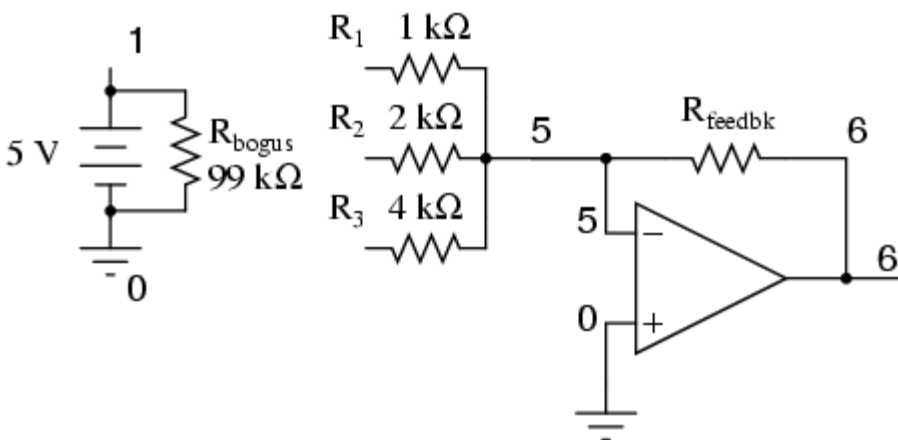
Starting from  $V_1$  and going through  $V_3$ , this would give each input voltage exactly half the effect on the output as the voltage before it. In other words, input voltage  $V_1$  has a 1:1 effect on the output voltage (gain of 1), while input voltage  $V_2$  has half that much effect on the output (a gain of 1/2), and  $V_3$  half of that (a gain of 1/4). These ratios were not arbitrarily chosen: they are the same ratios corresponding to place weights in the binary numeration system. If we drive the inputs of this circuit with digital gates so that each input is either 0 volts or full supply voltage, the output voltage will be an analog representation of the binary value of these three bits.



If we chart the output voltages for all eight combinations of binary bits (000 through 111) input to this circuit, we will get the following progression of voltages:

Binary	Output voltage
000	0.00 V
001	-1.25 V
010	-2.50 V
011	-3.75 V
100	-5.00 V
101	-6.25 V
110	-7.50 V
111	-8.75 V

Note that with each step in the binary count sequence, there results a 1.25 volt change in the output. This circuit is very easy to simulate using SPICE. In the following simulation, I set up the DAC circuit with a binary input of 110 (note the first node numbers for resistors  $R_1$ ,  $R_2$ , and  $R_3$ : a node number of "1" connects it to the positive side of a 5 volt battery, and a node number of "0" connects it to ground). The output voltage appears on node 6 in the simulation:



```

binary-weighted dac
v1 1 0 dc 5
rbogus 1 0 99k
r1 1 5 1k
r2 1 5 2k
r3 0 5 4k
rfeedback 5 6 1k
e1 6 0 5 0 999k
.end

```

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node  voltage      node  voltage      node  voltage
(1)   5.0000      (5)   0.0000      (6)  -7.5000

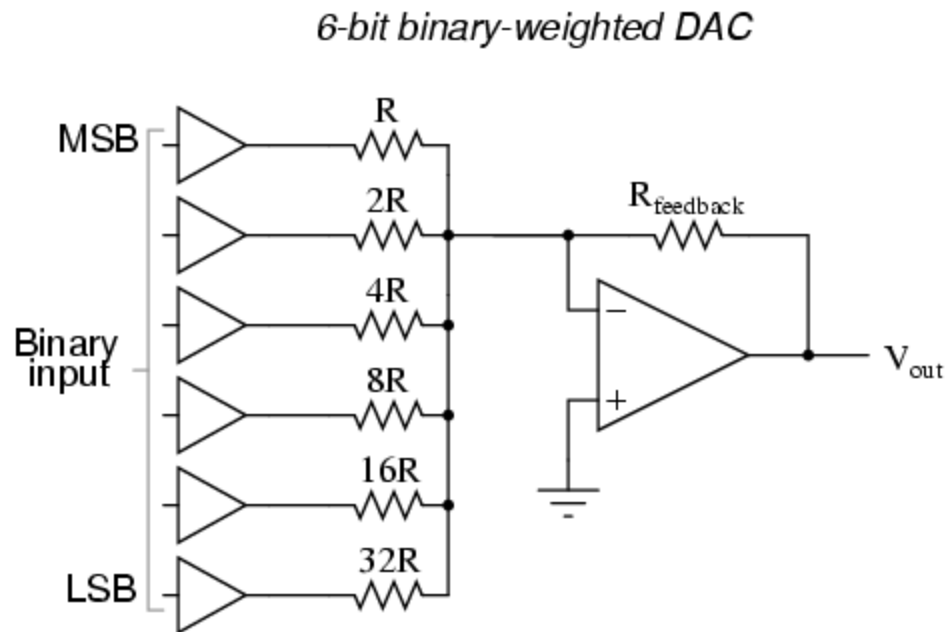
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We can adjust resistors values in this circuit to obtain output voltages directly corresponding to the binary input. For example, by making the feedback resistor  $800\ \Omega$  instead of  $1\ \text{k}\Omega$ , the DAC will output  $-1$  volt for the binary input 001,  $-4$  volts for the binary input 100,  $-7$  volts for the binary input 111, and so on.

(with feedback resistor set at  $800\ \text{ohms}$ )

Binary	Output voltage
000	0.00 V
001	-1.00 V
010	-2.00 V
011	-3.00 V
100	-4.00 V
101	-5.00 V
110	-6.00 V
111	-7.00 V

If we wish to expand the resolution of this DAC (add more bits to the input), all we need to do is add more input resistors, holding to the same power-of-two sequence of values:



It should be noted that all logic gates must output exactly the same voltages when in the "high" state. If one gate is outputting +5.02 volts for a "high" while another is outputting only +4.86 volts, the analog output of the DAC will be adversely affected. Likewise, all "low" voltage levels should be identical between gates, ideally 0.00 volts exactly. It is recommended that CMOS output gates are used, and that input/feedback resistor values are chosen so as to minimize the amount of current each gate has to source or sink.

Source: [http://www.allaboutcircuits.com/vol\\_4/chpt\\_13/2.html](http://www.allaboutcircuits.com/vol_4/chpt_13/2.html)