ECSE 331

Laboratory No. 2

Characterization of Some Basic Op-Amp Circuits

Objective:

Investigate the dynamic behavior of some typical op-amp circuits constructed using the 741 op-amp. Compare your results with that predicted by SPICE. Models of the electronic components can be found on the course web site.

Equipment Required:

1. NI Elvis-II$^+$ test instrument
2. PC with ELVIS-II$^+$ software installed
3. Components:
    a. 741 op-amp (LM741 from TI, UA741 from STMicroelectronics)
    b. resistors: 1kΩ, 2 kΩ, 4 kΩ, 8 kΩ, 10 kΩ, 16 kΩ, 100 kΩ
    c. capacitors: 0.22 μF

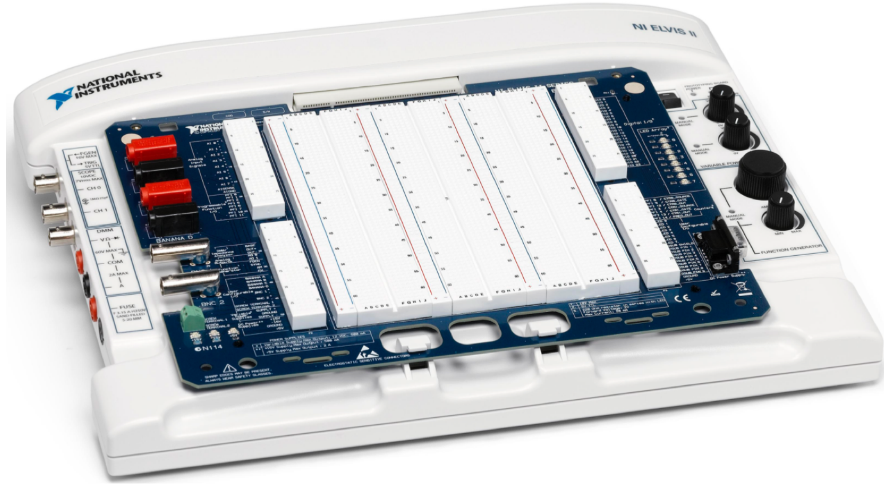
Description of the NI Elvis-II+ Test Instrument:

The National Instruments Educational Laboratory Virtual Instrumentation Suite (NI ELVIS-II$^+$) is a hands-on design and prototyping platform that integrates the 12 most commonly used instruments – including oscilloscope, digital multi-meter, function generator, bode analyzer, and more. It connects to a PC through a USB connection, providing quick and easy acquisition and display of measurements.

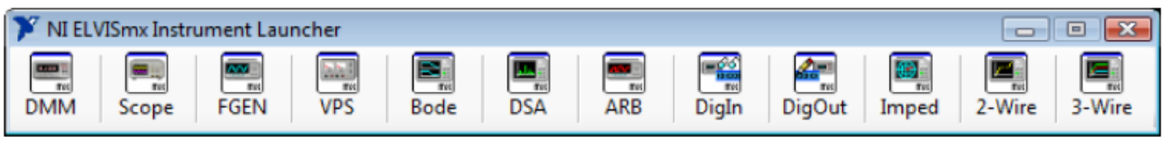
The National Instruments Educational Laboratory Virtual Instrumentation Suite consists of two main components:

1. The bench-top workstation (NI ELVIS-II$^+$), which provides instrumentation hardware and associated connectors, knobs, and LEDs as shown in Fig. 1(a). A prototyping board (breadboard) sits on top of the workstation, plugged into the NI ELVIS-II$^+$ platform, and offers hardware workspace for building circuits and interfacing experiments.
2. NI ELVIS-II$^+$ software, which includes soft front panel (SFP) instruments. Fig. 1(b) illustrates the PC screen view of the oscilloscope interface.

The Elvis-II$^+$ prototype board consists of 5 separate areas: four small prototype areas on the peripheral of the board, and a much larger central prototype area. The boards on the peripheral are used to interface to the internal data acquisition board of the Elvis-II$^+$ system. There are marking along the perimeter of the board indicating the connection. The student was introduced to this test bench back in Laboratory 1. The student should refer back to this lab for a detailed description of the NI ELVIS-II$^+$ test system.



(a)



(b)

Figure 1: (a) Elvis-II$^+$ instrumentation hardware with prototyping board, and (b) menu for various virtual instrument.

Practical Information for the Student:

In performing this experiment, you will construct several building blocks of modern transistor circuits. On doing so, keep the following points in mind:

1. In the figures, more positive voltages are always shown closer to the top of the page, so that current flows in the circuit from top to bottom.
2. Keep all connecting leads as short as possible and pushed down to the surface of the circuit board. You want to avoid a "*rat's nest*" of wiring whereby unwanted coupling capacitances and series inductances are created. These parasitics can prevent your circuit from working correctly.
3. Use different color wires in your circuit. The standard convention is red for positive supply voltages, blue for negative supply voltages and black for ground. Use colors that are different than these for signals. If you use a single color for everything, your circuit should still work. However, the debug process will be much more difficult if something goes wrong. It is important for the student to understand that when asked to design a circuit it is not limited to just the arrangement and component selection for the circuit but also to the fact that the design may not work the first time it is assembled. In general, all design will require at least two iterations before one can declare success!
4. In understanding circuits, as well as designing them, keep in mind that that there are two *interleaved* problems: the dc design, which establishes the operating points, and the ac design, which is responsible for how the circuit responds to signals. The student must design

both problems at the same time; if you make a change to one, be sure that you haven't changed the other.

Write-Up Requirements:

A good laboratory report should contain a **brief** description of what the experiment was about, including circuit diagrams, and what you did, your data, your results, and anything else called for in the assignment, such as questions inserted in the laboratory. Answers to these questions require observations that need to be made at the time you do the experiment.

The laboratory report should be written using the IEEE paper style consisting of a double-column single-space format, and must adhere to the following:

1. Title page - Title of the assignment/project, authors' name, and course name.
2. Abstract - Abstract of the assignment/project report.
3. Introduction
4. Main body of the assignment/project report including figures.
6. Conclusions
7. References
8. Appendices

Procedure:

Connect the following circuits using the 741 op-amp with pin-outs shown in Fig. 2.

1) ***Comparator*** (Fig. 3). Apply a 1 kHz sine-wave of about 1 Vpp to the noninverting (+) input with the inverting (-) input grounded. Observe this signal on the oscilloscope through channel A, set the trigger to external and capture the output on channel B. *Does it change if you reduce the input amplitude to 0.1 V? What is the effect of grounding the + input terminal, and connecting the signal to the – input terminal?*

(2) ***Voltage Follower*** (Fig. 4): Apply the same signal to the input as in part 1. Note that with negative feedback (output to the – input terminal) the op-amp will adjust its output so that the inverting input is at the same voltage as the noninverting input. *What is the signal at the output? What is the input impedance of the circuit? Justify your answer with actual measured data. What happens with a square-wave input?*

(3) ***Noninverting Amplifier*** (Fig. 5): Apply the same signal as in part 1 to the input of the noninverting amplifier shown in Fig. 5. *What is the signal at its output? What is the signal at the inverting input terminal to the op-amp? What is the gain of the amplifier? Be precise. If the input signal amplitude is increased what happens at the output of the amplifier? What happens with a square-wave input with a 1 Vpp amplitude? Change the circuit so that it realizes a gain of 10 V/V and show that it operates correctly.*

(4) ***Inverting Amplifier*** (Fig. 6): With the input to this amplifier grounded, measure the voltage at the inverting input terminal to the op-amp. This terminal is said to be at a "virtual ground." Apply the same signal as in part 1, observe the output signal with respect to the input signal in a manner like that performed in part 1. *What is the gain of the circuit? What do you observe at the output of this amplifier if the inverting input terminal to the op-amp is connected to "real" ground? How would you change this circuit to make the magnitude of the gain equal to 10 V/V?* The input impedance of a circuit is the ratio of the input voltage to the input current. With a 5 Vpp input, compute the current

flowing through the 1-kΩ resistor. *What is the input impedance to this circuit?*

(5) ***Differentiator*** (Fig. 7): This circuit differentiates the input voltage signal. Since the inverting input is at a virtual ground, the current that flows through the 0.2-μF capacitor is proportional to the derivative of the input voltage signal, i.e.,

$$i_C = C\frac{dv_{IN}(t)}{dt} = 0.2\times10^{-6}\frac{dv_{IN}(t)}{dt}$$

As this current passes directly through the 1-kΩ feedback resistor, the output voltage will be proportional to the derivative of the input voltage, i.e.,

$$v_O(t) = -R\times i_C = -R\times C\frac{dv_{IN}(t)}{dt} = -0.2\times10^{-3}\frac{dv_{IN}(t)}{dt}$$

Apply the same signal as in part 1 to the input of the differentiator and observe the output signal. Set the trigger on the oscilloscope carefully. *Superimpose the input and output signals on the same plot and observe any differences. Repeat with a triangular wave input.*

(6) ***Integrator*** (Fig. 8): In this circuit the capacitor and the resistor are interchanged from those in the differentiator circuit of Fig. 7, resulting in a circuit that produces an output, which is proportional to the integral of the input signal, i.e.,

$$v_O(t) = -\frac{1}{R\times C}\int_0^t v_{IN}(\tau)d\tau = -\frac{1}{0.2\times10^{-3}}\int_0^t v_{IN}(\tau)d\tau$$

In order to stabilize the circuit at DC, an additional 100-kΩ resistor has been placed across the feedback capacitor. Apply the same signal as in part 1 to the input of the integrator and observe the output signal. Set the trigger on the oscilloscope carefully. *Superimpose the input and output signals on the same plot and observe any differences. Repeat with a square-wave wave input.*

(7) ***D/A Converter*** (Fig. 9): The circuit shown in Fig. 9 is a 4-bit digital-to-analog (D/A) converter circuit. In essence, it consists of an inverting amplifier with four separate inputs. As the inverting input is held at virtual ground, currents from the four inputs are added and flow together into the output feedback resistor. The value of four input resistors have been chosen so that each contributes approximately twice as much current as the previous one, beginning with input 1. With a +5 V input signal, close the switch to each feed-in resistor in accordance to the Table 1, and observe the corresponding output voltage. A 0 indicates a switch is opened and a 1 indicates that the switch is closed.

Plot the output voltage of the D/A converter (y-axis) as a function of the integer value of the digital control signal. Join the two end points with a straight-line, and observe the maximum distance the measured points deviates from the straight-line.

This concludes this lab.

Table 1: D/A Converter Switch Arrangement

Integer	Switch Arrangement $b_3b_2b_1b_0$
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

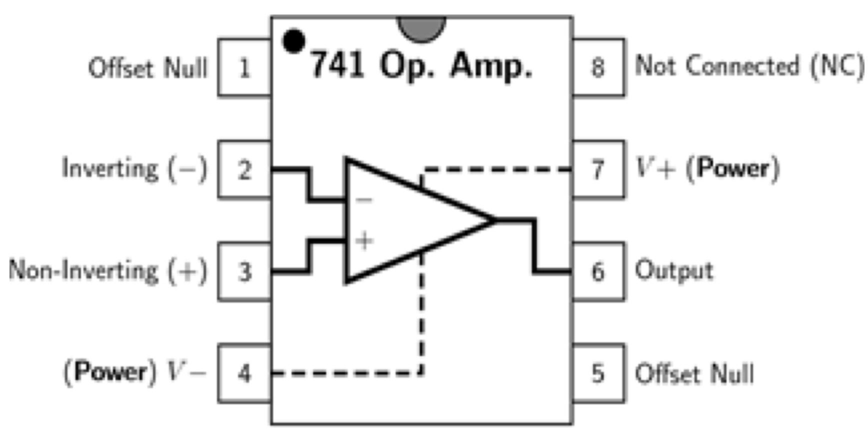


Fig. 2: 741 Pin-Out

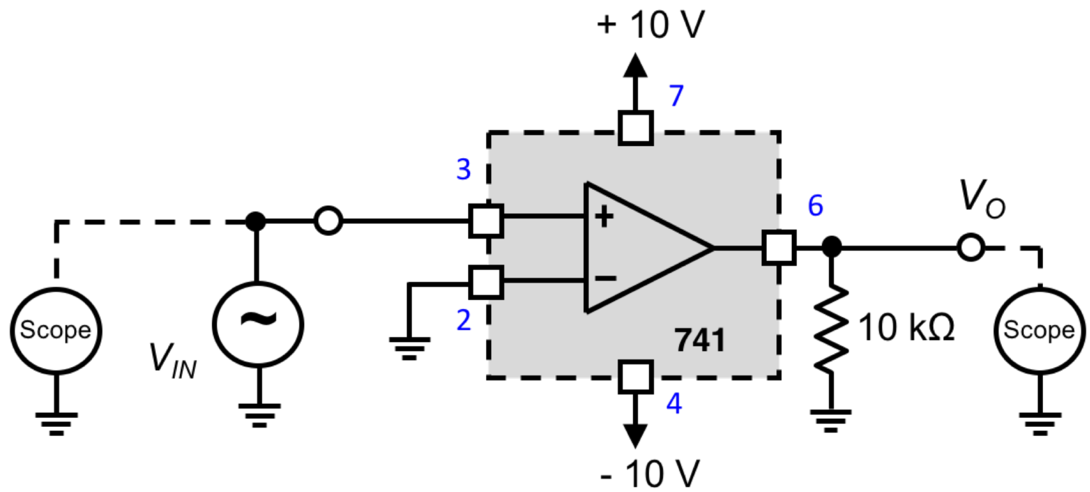


Fig. 3: Comparator

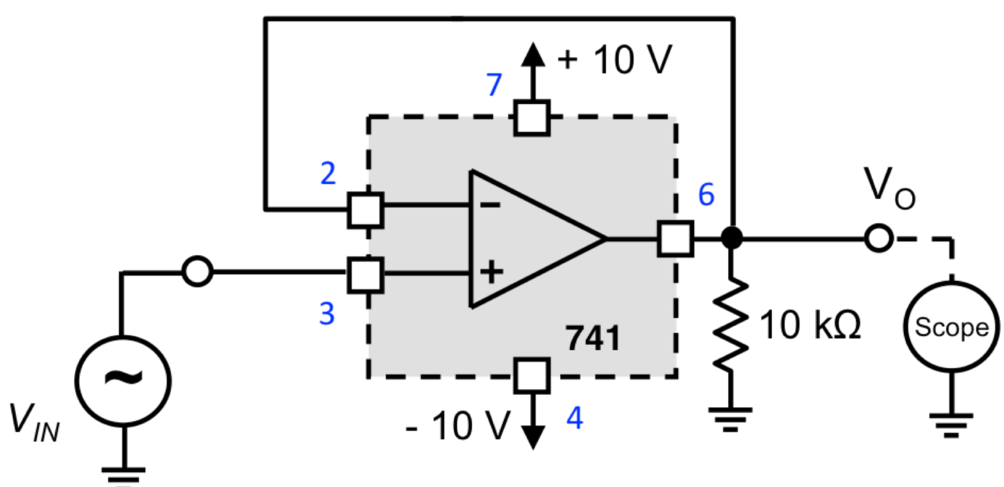


Fig. 4: Voltage Follower

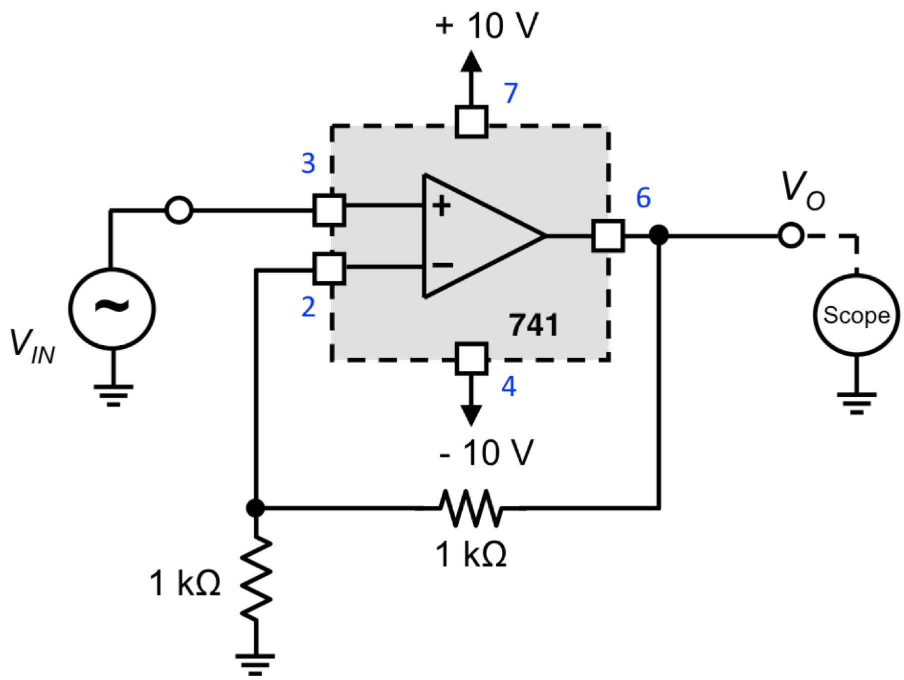


Fig. 5: Noninverting Amplifier

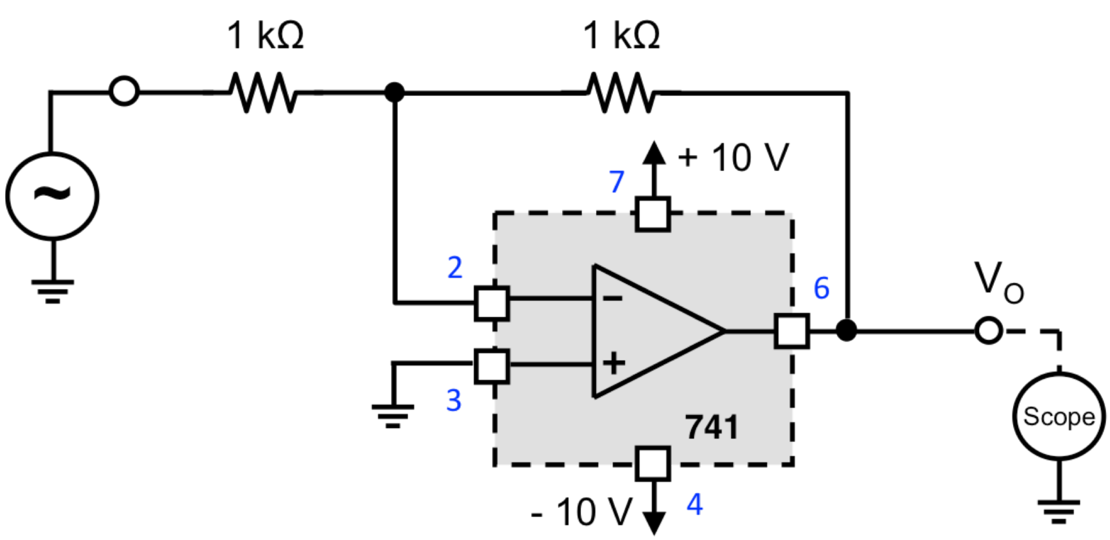


Fig. 6: Inverting Amplifier

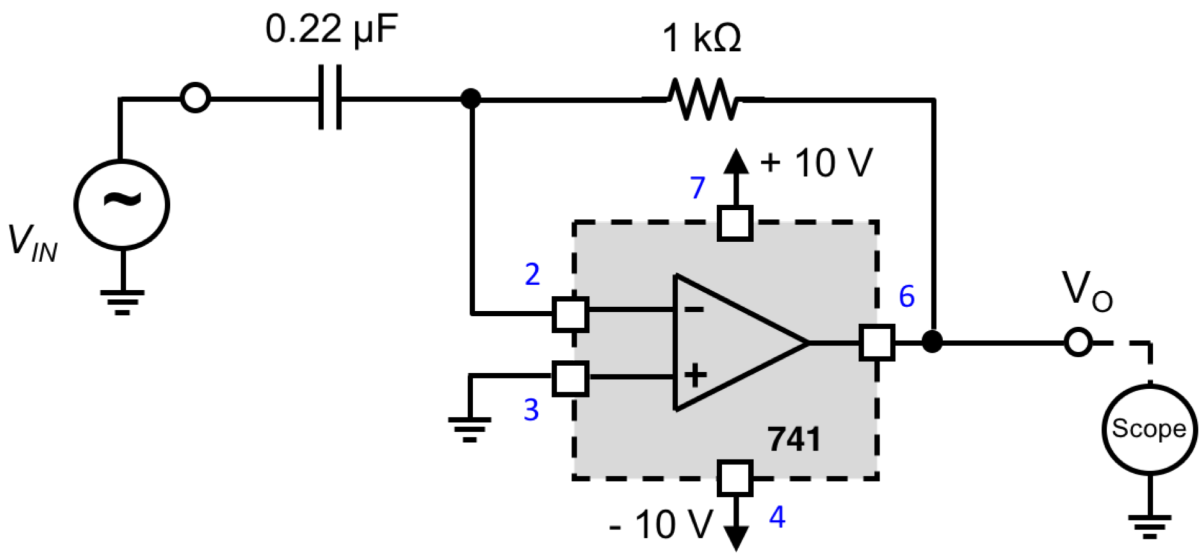


Fig. 7: Differentiator

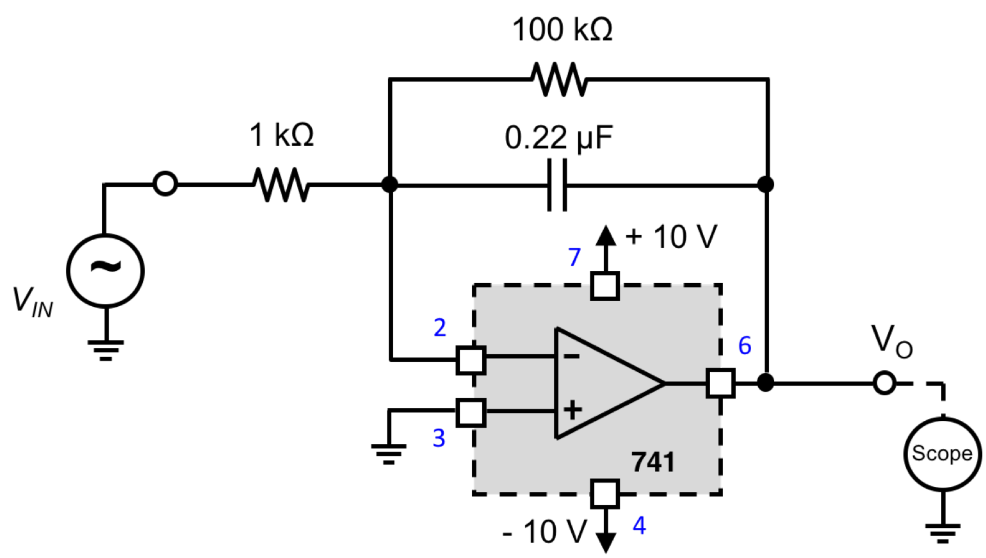


Fig. 8: Integrator

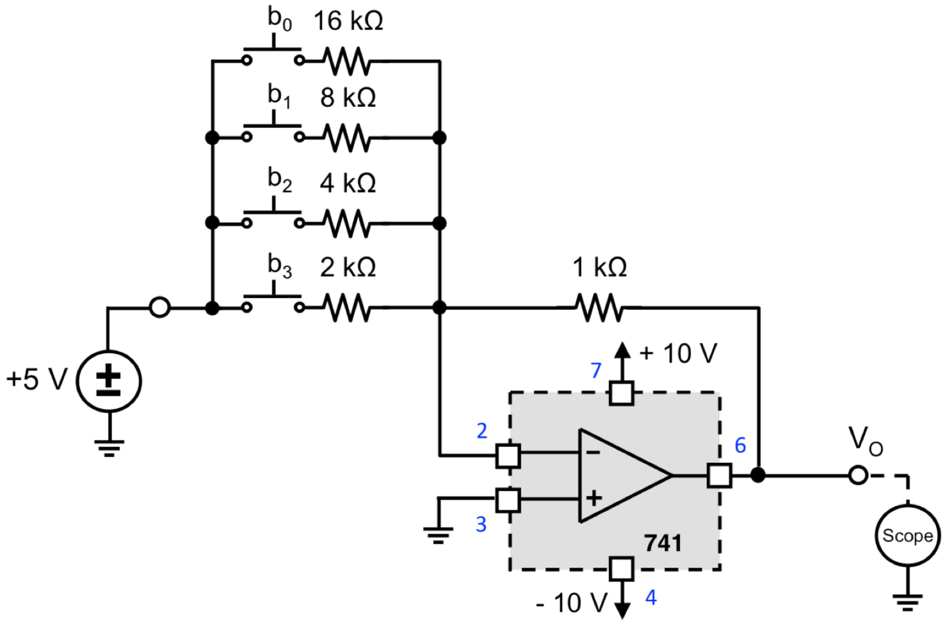


Fig. 9: D/A Converter