Overview:

In this lesson, students will learn how to use an analog input on the TI-Innovator™ Hub to sense and measure a variable voltage. Students will construct a circuit using a Potentiometer with Knob to produce a variable voltage and write a TI-Basic program to measure and display the output voltage from the Potentiometer with Knob. In addition, students will learn about voltage divider circuits and how to calculate the output voltage produced by that type of circuit.

Goals:

1. Build a circuit on a breadboard with a Potentiometer with Knob and connect it to an analog input pin on the TI-Innovator Hub.
2. Author a TI-Basic program on a calculator that periodically reads an analog input from the circuit and then calculates and displays the output voltage from the circuit.
3. Calculate the output voltage produced from any voltage divider circuit.

Background:

Almost all entertainment media today is digital. Music and video files that are stored on CD, DVD, downloaded, or streamed are all forms of digital data that are easily processed by computer chips. But how can that be?

In Units 1 and 2 students learned that digital means a signal is either on or off, that is, there are only two values. Yet, in music there are many different notes in a song and in video there are many different shades and colors in a scene. Music and video are called analog signals and those signals vary continuously like some math function or the number line.

Computers are digital and have only two states, 0 or 1. Analog input on the TI-Innovator Hub is a process that makes a rapid conversion of analog signals into digital signals. This is accomplished by using many 0 and 1s to represent a single analog value. Groups of 0s and 1s are called binary numbers.

Binary numbers are just as valid as base 10 numbers that are used every day; and in math class, students might learn how to convert between them. For example, the number 1001 in binary is exactly equal to the number 9 in base 10. This is because in the binary system, **1001** is really $\mathbf{1}\times2^3 + \mathbf{0}\times2^2 + \mathbf{0}\times2^1 + \mathbf{1}\times2^0$ or 8 + 0 + 0 + 1 = 9. Any decimal number can be expressed in binary; however, the equivalent binary number will always have more digits than the decimal number.

When an analog signal (variable voltage) is connected to an analog input on the TI-Innovator Hub, the changing continuous values are very rapidly converted into samples of large binary numbers. The process of streaming these digital numbers can create quite a lot of data. This is why music and video files are so huge compared with a word processing or spreadsheet file.

In unit 3, students learned about analog output. That method does the exact opposite of analog input—it converts a digital number into a continuous voltage signal. Remember analog output requires a number from 0 to 255? The number 255 is important in computer science because it is the largest decimal value that can be expressed by an 8-bit binary number, sometimes called a “byte”. The 8 digits binary number 11111111 is equal to 255.

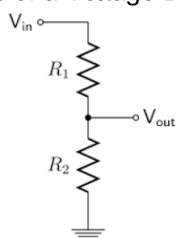
The analog input on the TI-Innovator Hub uses 14-bit values. A 14-bit binary number can range from 0 to 16,384. So, when a continuous analog voltage is placed on an analog input pin on the TI-Innovator Hub, it is very rapidly converted into a number that ranges from 0 to 16,384.

In this lesson, students will use analog input to measure the voltage of a Potentiometer with Knob—a device that can vary voltage from 0 to 3.3V by simply turning a knob. Next time you listen to music or watch an online video, remember that the original sound or light signal was very quickly sampled and turned into a stream of binary numbers by a computer and stored in an extremely large file that is then converted back into an analog signal when you watch or listen!

In this lesson, students will build a circuit that can change one voltage value into a different voltage value using a Potentiometer with Knob, an electrical device that uses a special circuit called a voltage divider. A voltage divider can turn a large voltage into a smaller one. It is built using two resistors in series with an input voltage applied.

By dividing the input voltage by some fraction, a smaller output voltage can be produced. The ratio between the two resistors inside the potentiometer is changed when the knob is turned, thus changing the output voltage. This smaller output voltage can then be measured using the analog input pin on the TI-Innovator Hub. Below you will learn more about a voltage divider.

A Schematic of a Voltage Divider Circuit

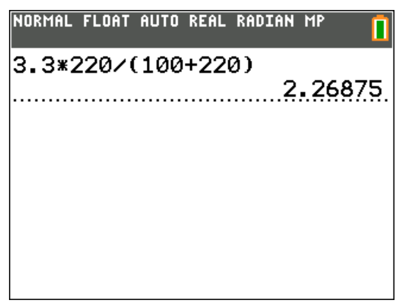


Formula to calculate the output voltage of a voltage divider circuit based on the values of the two resistors in the circuit labeled R_1 and R_2.

$$V_{out} = V_{in} \frac{R_2}{R_1 + R_2}$$

Practice:

What is the output voltage when a voltage divider circuit is built with R_1 = 100Ω and R_2 = 220Ω and is connected to a 3.3V supply input?



The output voltage is changed from 3.3V to 2.27V when the current passes through the circuit.

Try another:

What is the output voltage when a voltage divider is built with R_1 = 1000Ω and R_2 = 470Ω and is connected to a 12V supply input?

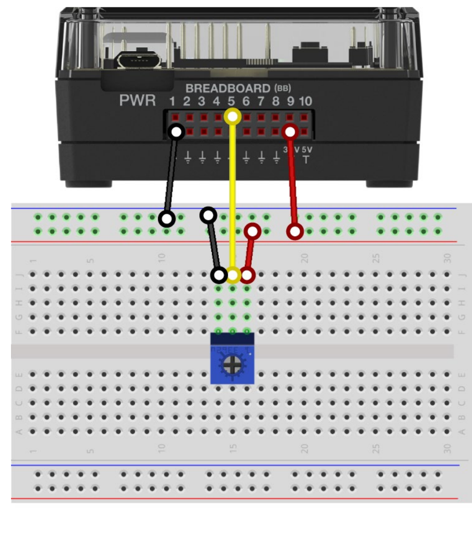
Answer: 12*(470/1000+470))=3.84V

Materials and Tools

- TI-84 Plus CE
- TI-Innovator Hub with USB Cable
- Voltmeter (optional)
- TI-Innovator Breadboard Pack:
  - Breadboard
  - Male to Male Jumper Cables
  - Potentiometer with Knob
  - Resistor 100 Ohm (brown, black, brown)

Build the Hardware:

Assemble the circuit in the diagram by following these steps:



1. Place the Potentiometer with Knob on the breadboard. Be sure each leg is in a different column.
2. Use a yellow Male to Male Jumper Cable to connect from BB5 (an analog input) on the TI-Innovator Hub to the center leg of the Potentiometer with Knob.
3. Use a black Male to Male Jumper Cable to connect the left leg of the Potentiometer with Knob to any ground pin on the blue ground breadboard bus.
4. Use a red Male to Male Jumper Cable to connect the right leg of the Potentiometer with Knob to the 3.3V red breadboard bus.
5. Use a red Male to Male Jumper Cable to connect the red breadboard bus to the 3.3V pin on the TI-Innovator Hub.
6. Use a black Male to Male Jumper Cable to connect the blue breadboard bus to any ground pin on the TI-Innovator Hub.
7. Plug the B end of the “unit to unit” USB cable into the TI-Innovator Hub and then the A end into the handheld device.

Tech Tip: It is important to demonstrate to students how to be methodical when checking for hardware errors. Show them how to trace the current through the circuit and the requirement for a complete circuit from source to ground. A common problem is an incorrect placement of the Potentiometer with Knob or an incomplete circuit due to wrong jumper wire placement on the breadboard. Analog inputs are only supported on BB5, BB6, BB7, IN1, IN2, and IN3. Notice that swapping the outer legs (3.3V and Ground) of the Potentiometer With Knob switches the direction the voltage changes when knob is turned.

Write the Software:

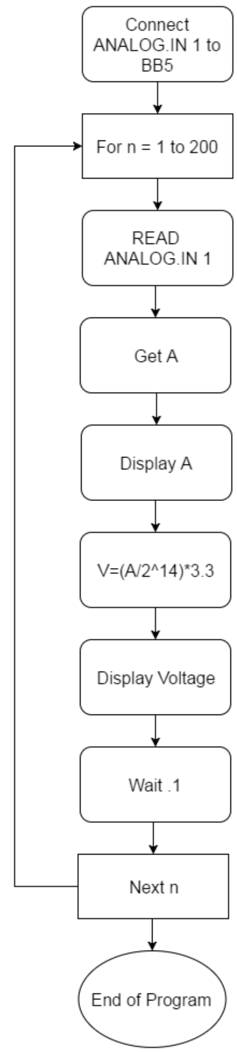
Task: Write a TI-Basic program on the handheld that will read an analog input (BB5) connected to the Potentiometer with Knob and display the output voltage. Use the following formula to convert the analog input value into voltage. Remember the TI-Innovator Hub converts voltages into 14-digit binary numbers that have a maximum value of 2^{14}. Also, the Potentiometer with Knob input voltage from the TI-Innovator Hub is 3.3V. This formula will convert the 14-bit "raw" analog input value into volts.

$$V = \frac{A}{2^{14}} \cdot 3.3$$

Explore how turning the knob changes the voltage. Can you figure out how to reverse the effect of turning the knob in hardware? How about in software?

Example Code

```
Send("BEGIN"):Get(Str0):Disp Str0
Send("CONNECT ANALOG.IN 1 TO BB 5")
For(N,1,200)
Send("READ ANALOG.IN 1")
Get(A)
Disp "ANALOG in = ",A
(A/2^14)*3.3 ->V
Disp “VOLTAGE =”,V
Wait .1
End
```



Extra For Experts:

1. Use the schematic on the right and the voltage divider formula to calculate the output voltage of this circuit.
2. Build the circuit on the breadboard. Connect the voltage divider to the 3.3V and ground on the TI-Innovator Hub, and connect V_{out} to BB5.
3. Use the TI-Innovator Hub and the above program to measure the output voltage (V_{out}) of the voltage divider circuit. How close are the calculated and measured values?
4. If available, measure the voltage output with a voltmeter and see how close this value agrees with the TI-Innovator Hub and your program.