

Electronics at school beyond the bulb with TI-Innovator Vs. 1.2

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Abstract

In many Swiss schools pre-university students are still introduced to electric circuits by means of the traditional Edison light bulbs, the so called "Lämpfipraktika" (Swiss idiom for "Practicing with light bulbs"). Not the best method, if we consider that traditional bulbs are no longer allowed and that electronics have changed since Edinson's times!

In this workshop a number of simple experiments with the TI-Innovator microcontroller system, the TI-Nspire programming and actual electronic and electric components are presented: SPDT- and DIP-switches, discrete LEDs, 7-segment LED displays (red and blue), relays, resistors, rectifiers, thermistors etc. This workshop is inspired by Ed. Doerings NI-myRIO «project essentials guide» (National Instruments, LabVIEW). <http://www.ni.com/academic/myrio/project-guide.pdf>

Introduction





In this paper an introductory workshop to modern electronics for non-technological oriented pre-university schools with the TI-Innovator microcontroller interface and the TI-84, TI-Nspire calculators or the TI-Nspire software is presented. In a step-by-step method students without any knowledge in electronics learn to understand and to build simple computer controlled electronic circuits with discrete electric and electronic components.





About Innovator: Functionality of the 10 BB Pins, addressable Components


https://education.ti.com/html/webhelp/EG_Innovator/EN/content/eg_innovsys/m_hub-datasheets/hub_ds_hubportsusablepins.HTML

Pin	Digital I/O	Pulse Width Modulation (PWM)	ANALOG IN 14 Bit ADC
BB1	Y		
BB2	Y		
BB3	Y		
BB4	Y	Y	
BB5	Y		Y
BB6	Y		Y
BB7	Y		Y
BB8	Y	Y	
BB9	Y	Y	
BB10	Y	Y	

See also: Breadboard Components and Usable Pins

7-segment Display		BB 1-10
Small DC Motor		BB 1-10 (uses digital to generate software PWM)
TTL Power MOSFET		BB 1-10
TI Analog Temperature Sensor		BB 5,6,7 (analog input required)

Component	Image	Used with pins
Red LEDs		BB 1-10
Green LEDs		BB 1-10
RGB (Red-Green-Blue) LEDs		BB 8-10
Thermistor		BB 5,6,7 (analog input required)

Visible Light Sensor		BB 5,6,7 (analog input required)
Infrared Transmitter LTR-302, yellow dot		BB 1-10 (digital output)
Infrared Receiver LTR-301, red dot		BB 1-10 (digital input)

1. Discrete LED, introduction and learning objectives

1.1. Introduction

LEDs, or light-emitting diodes, provide simple yet essential visual indicators for system status and error conditions. Figure 1 shows some typical LEDs; green, red, and RGB-LEDs are included in the TI-Innovator™ Breadboard Pack, a white LED in the I/O-modules Pack.



Figure 1: Typical LEDs

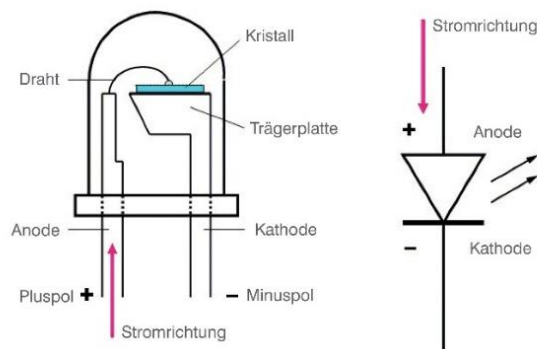


Figure 2 LED Function and Symbol

1.2 Learning Objectives

After completing this activity you will be able

1. to describe the essential concepts related to LEDs :

- A LED is a diode that permits only one-way current,
- The LED forward-bias voltage drop varies with color (wavelength of the emitted light),
- The interface circuit design depends on knowledge of the TI-Innovator's Breadboard (BB1 to BB10) output resistance and source voltage (3.3 V or 5 V).

(d) blue LEDs may be direct-connected to the TI-Innovator's Breadboard (BB1 to BB10) outputs.

2. to select a suitable current-limiting resistor (or no resistor) based on the LED type.

3. to create a LED variable-intensity dimmer with one of the Innovators PWM Pins (BB4, BB8, BB9 or BB10) to create a pulse-width modulated digital output

1.2. Component Demonstration

Follow these steps to demonstrate correct operation of the discrete LED component :

Select these parts from the TI Innovator Breadboard Pack:

- one 100 Ohm resistor
- a two-terminal LED
- Innovators breadboard
- Jumper wires

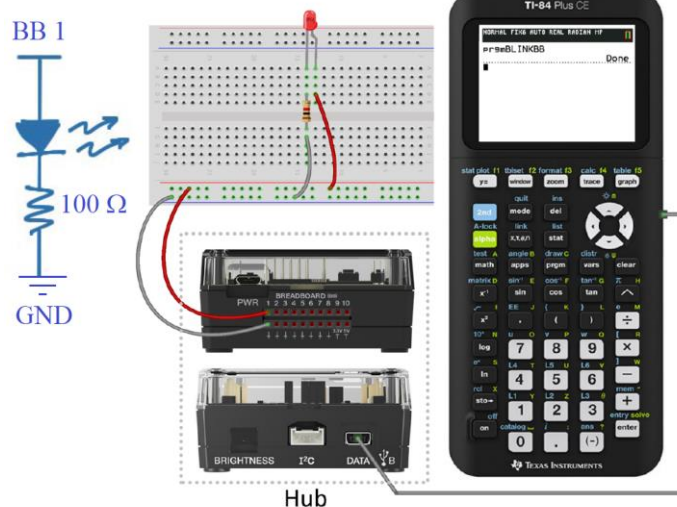
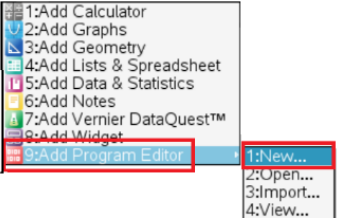
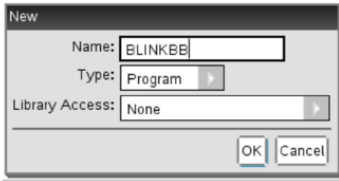

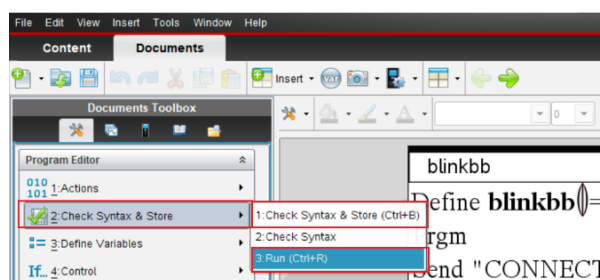


Figure 3 schematic diagram and wiring

Program : **Blinking 10 times** (TI-Nspire CX CAS-Software / PC)

Preparation	Innovator Program BB 1	Innovator Program OUT 1
<p>1,2</p>  <p>3</p>  <p>4</p> 	<pre> Define blinkbb()= Prgm Send "CONNECT LED 1 TO BB 1 " For n,1,10 Send "SET LED 1 OFF" Wait 1 Send "SET LED 1 ON" Wait 0.1 EndFor Send "DISCONNECT LED 1" EndPrgm </pre>	<pre> Define white_led()= Prgm Send "CONNECT LED 1 TO OUT 1" For n,1,10 Send "SET LED 1 OFF" Wait 1 Send "SET LED 1 ON" Wait 0.1 EndFor Send "DISCONNECT LED 1" EndPrgm </pre>

Syntax Check and Execution



All of the LEDs in the Breadboard Pack have clear plastic lenses with a wide variety of colors. You may wish to try multiple LEDs to investigate your color options.

Because this interface circuit is the **current sourcing form** the LED is active when the digital output is in the high state, i.e., this is an **active-high** LED interface circuit.

Try the current sinking (active low) circuit (Fig. 5).

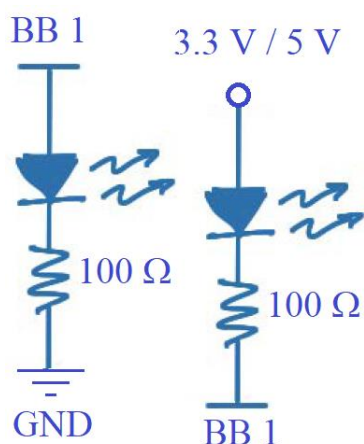


Figure 4 current sourcing (active high, left) and current sinking (active low, right)

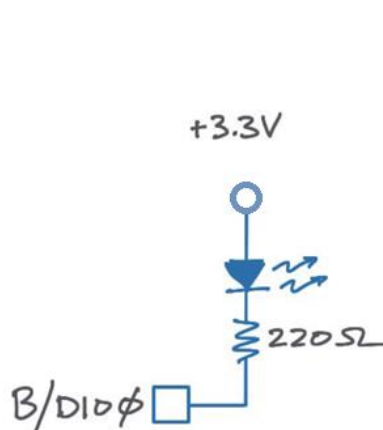
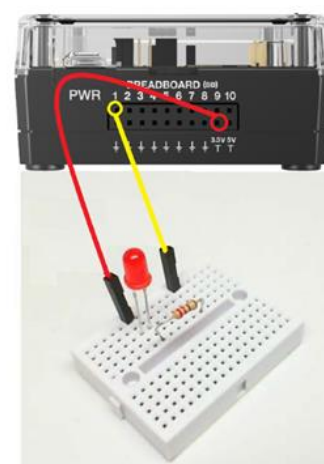


Figure 5 current sinking (active low) circuit



Troubleshooting tips:

Not seeing the expected results? Confirm the following points:

- Correct LED orientation — the diode conducts current in one direction only; remove the LED and reinsert it in the opposite direction
- Correct resistor value — use an ohmmeter to verify that the resistor is near 100 ohms.

⇒ The ON-signal of the SET-LED 1-instruction is *not* a 3.3 Volt DC-signal but an 500 Hz square wave with a duty cycle of 50

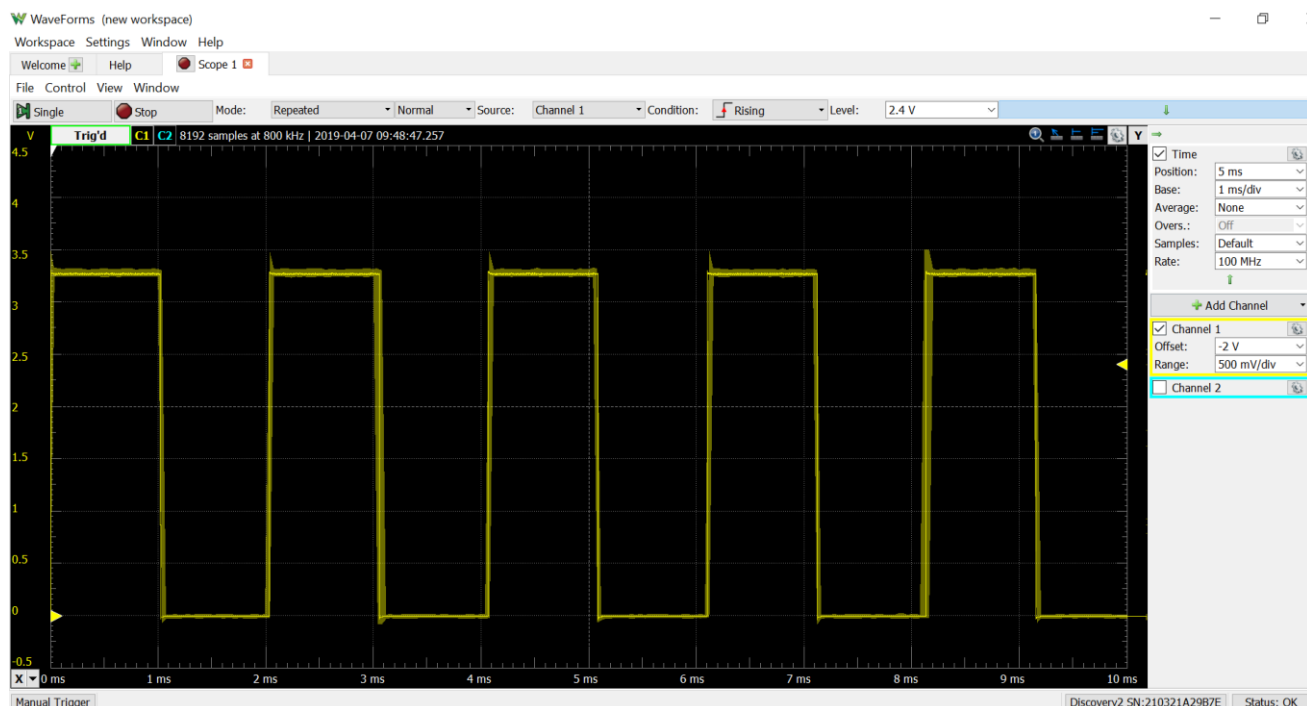


Figure 6 the on-state of the TI-Innovator-output (e.g. BB1) is a 50% duty-cycle 490 Hz square-wave !

1.4. Basic Modifications

1. Add an input control to adjust the blink frequency specified in Hertz; at what frequency does the blinking become imperceptible?

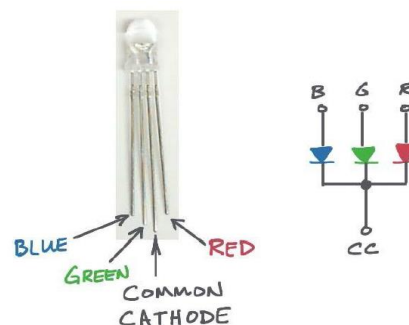
Try the instruction `Send "SET LED 1 ON TOGGLE 10 TIME 10"` or
`Send "SET LED 1 ON BLINK 10 TIME 10"`

2. Blink two adjacent LEDs to simulate a railroad crossing signal.

3. Blink the green and blue LEDs of the RGB LED using the same code as the railroad crossing signal; refer to Figure 5 for the RGB LED pinout diagram.

Use the current-sourcing interface circuit.

Figure 5 RGB LED pinout diagram



4. Create a LED variable-intensity dimmer with one of the PWM Pins (BB4, BB8, BB9 or BB10) to create a pulse-width modulated digital output (see Figure 5).

Try the instruction Send "SET LED 1 #" where # is a integer between 0 and 255 for the duty-cycle of the pulse-width modulated signal, 0 for OFF (0% Duty Cycle), 255 for ON (100% Duty Cycle)

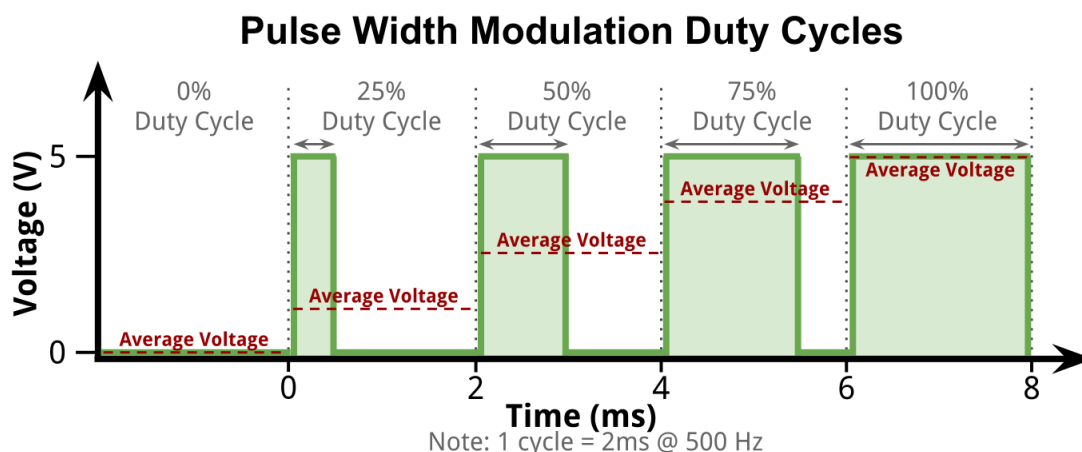
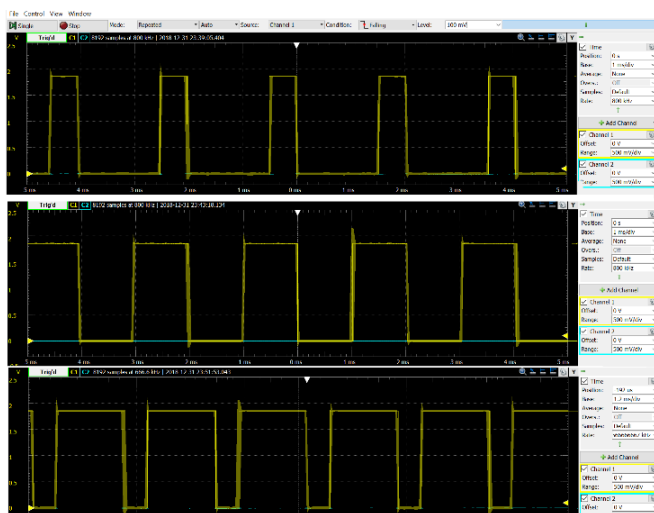


Figure 5 Pulse Width Modulation (PWM): Duty Cycles from 0% to 100%



Innovator PWM-Program with a duty cycle of 191 (0 ... 255)

```
Define blinkbb(=
Prgm
  Send "CONNECT LED 1 TO BB 4 "
  Send "SET LED 1 eval(191)"
  Wait 60
  Send "DISCONNECT LED 1"
EndPrgm
```

Figure 6 25%, 50% and 75% Innovator's dutycycle pulse width modulation signal at 490 Hz (measured with Analog Discovery 2, Digilent)

2. Seven Segment LED Display

2.1 Introduction

Displays based on seven LED segments arranged in an "8" pattern provide a simple means to display numbers 0 to 9 and some letters of the alphabet. Figure 1 shows the Breadboard Pack seven-segment display.

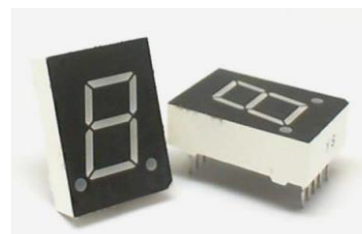


Figure 1 Seven segment LED Displays

2.2 Learning Objectives

After completing the activities in this chapter you will be able

1. to describe the array of LEDs wired with a *common-cathode* connection,
2. to design the interface circuit by applying knowledge of the Innovator BB-pins output resistance, source voltage, LED voltage-current characteristic, and

3. to recognize that red LEDs must be connected with current-limiting resistors to the TI-Innovator BB pins while blue LEDs may be direct connected without current-limiting resistors.

2.3 Component Demonstration

Select these parts from the TI Innovator Breadboard Pack:

- Seven-segment LED display
- Breadboard
- 100 Ohm resistors
- Jumper wires

Build the interface circuit: Refer to the pin diagram and recommended breadboard layout shown in Figure 2 and 3.

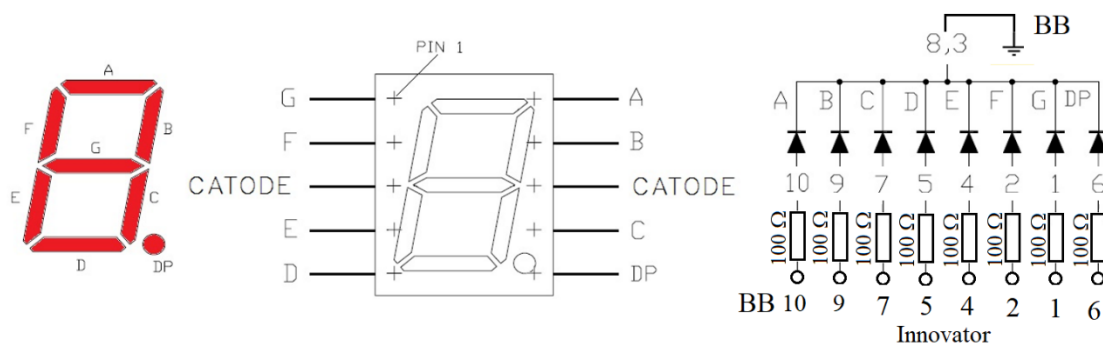


Figure 2 LTS-4301JR common cathode seven segment display (Al-In-Ga-P super red)

The interface circuit requires nine connections to TI Innovator (see Figure 2):

- | | |
|--------------------------------|-----------------|
| 1. Common cathode Pins 3, 8 => | Innovator Gnd |
| 2. Segment A, Pin 10 => | Innovator BB 10 |
| 3. Segment B, Pin 9 => | Innovator BB 9 |
| 4. Segment C, Pin 7 => | Innovator BB 7 |
| 5. Segment D, Pin 5 => | Innovator BB 5 |
| 6. Segment E, Pin 4 => | Innovator BB 4 |
| 7. Segment F, Pin 2 => | Innovator BB 2 |
| 8. Segment G, Pin 1 => | Innovator BB 1 |
| 9. Decimal point, Pin 6 => | Innovator BB 6 |

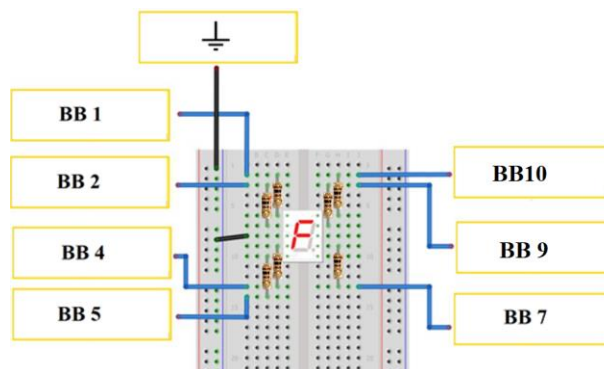


Figure 3 breadboard wiring with 100 Ohm resistors

The following program «seven_segment()» lightens all 7 segment- and the decimal-point-LED for 5 seconds. To start the 8 LEDs are connected to the Innovator breadboard pins BB1 to BB10. Pin BB3 and BB8 are not used. Then the 8 pins are switches on, after 5 seconds the 8 pins are switched off.

Innovator Programs

```

Define seven_segment(=
Prgm
© program enlighs all 7 segments and the decimal point of
a 7-segment LED display. LED 3 and LED 8 are not wired.

For i,1,10
Send "CONNECT LED eval(i) TO BB eval(i) "
EndFor

For i,1,10
Send "SET LED eval(i) ON "
EndFor

Wait 5
For i,1,10 Send "DISCONNECT LED eval(i)"
EndFor EndPrgm
    
```

The following program «seven_segment2() allows to enter numbers from 0 through 9 and to show them on the 7 segment LED display. If other numbers are entered a decimal point will be shown.

```

Define seven_segment2(=
Prgm
:© program shows the input number entered on the 7-segment display
: For i,1,10
:   Send "CONNECT LED eval(i) TO BB eval(i) "
: EndFor
:: Text "input one number from 0 to 9"
:   Request "number",n
:   If n=0 Then
:     For i,1,10
:       If not (i=1) and not (i=6) Then
:         Send "SET LED eval(i) ON "
:       EndIf
:     EndFor
:   EndIf
:   If n=1 Then
:     Send "SET LED 7 ON "
:     Send "SET LED 9 ON "
:   EndIf
:   If n=2 Then
:     For i,1,10
:       If not (i=2) and not (i=6) and not (i=7) Then
:         Send "SET LED eval(i) ON "
:       EndIf
:     EndFor
:   EndIf
:   If n=3 Then
:     For i,1,10
:       If not (i=2) and not (i=4) and not (i=6) Then
:         Send "SET LED eval(i) ON "
:       EndIf
:     EndFor
:   EndIf
:   If n=4 Then
:     Send "SET LED 1 ON "
:     Send "SET LED 2 ON "
:     Send "SET LED 7 ON "
:     Send "SET LED 9 ON "
:   EndIf
:   If n=5 Then
:     For i,1,10
:       If not (i=4) and not (i=6) and not (i=9) Then
:         Send "SET LED eval(i) ON "
:       EndIf
:     EndFor
:   EndIf
:   If n=6 Then
:     For i,1,10
:       If not (i=6) and not (i=9) and not (i=10) Then
:         Send "SET LED eval(i) ON "
:       EndIf
:     EndFor
:   EndIf
:   If n=7 Then
:     Send "SET LED 7 ON "
:     Send "SET LED 9 ON "
:     Send "SET LED 10 ON "
:   EndIf
:   If n=8 Then
:     For i,1,10
:       If not (i=6) Then
:         Send "SET LED eval(i) ON "
:       EndIf
:     EndFor
:   EndIf
:   If n=9 Then
:     For i,1,10
:       If not (i=4) and not (i=5) and not (i=6) Then
:         Send "SET LED eval(i) ON "
:       EndIf
:     EndFor
:   EndIf
:   If not (n=0) and not (n=1) and not (n=2) and not (n=3)
:   and not (n=4) and not (n=5) and not (n=6) and not (n=7)
:   and not (n=8) and not (n=9) Then
:     Send "SET LED 6 ON "
:   EndIf
:   Wait 5
:   For i,1,10
:     Send "DISCONNECT LED eval(i)"
:   EndFor
:EndPrgm

```

2.4 Interface circuit Theory

Each of the seven line segments as well as the decimal point is an individual red LED, each with its own anode and cathode. To conserve the number of electrical connections on the display all of the eight cathodes are tied together and brought out as the “common cathode” pin 8 and 3. Figure 7 shows the voltage-current characteristics of LEDs with colours from infrared to ultraviolet. We work with red LEDs @ 1.7 V, 16 mA and a current limiting 100-Ohm resistor with a voltage drop of $100\ \Omega \cdot 0.017\ \text{A} = 1.7\ \text{V}$. With a blue 7-segment LED display no resistors are required at all if we work e.g. with at 3.3 V and 46 milliamps (Figure 7). But it must be of a **common cathode** type,

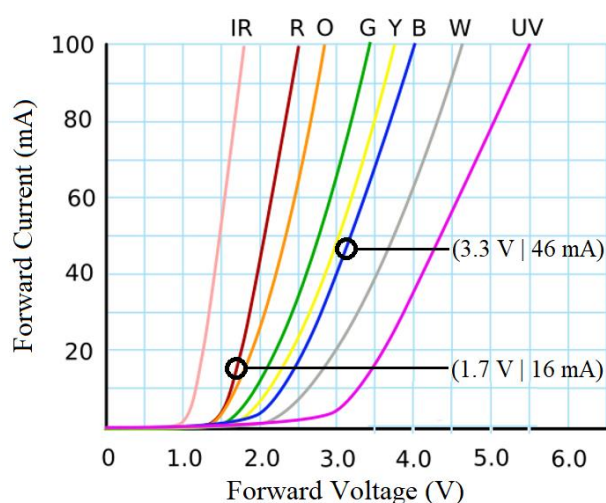


Figure 4 LED Voltage Current characteristics for IR-, red-, orange-, green-, yellow-, blue-, white- and UV-LEDs,

e.g. SC10-21QBWA-D (Kingbright). Seven segment **blue** LED displays (not included in Innovators breadboard pack) are better suited for student work than the LTS-4301JR seven segment **red** LED display in the breadboard pack because no troublesome wiring of resistors is necessary.

2.4 Twyman Fonts

World's Simplest Twyman TrueType font for seven-segment displays; use this to quickly translate your text phrases into suitable segment patterns.

Problems: K vs. H, 9 vs. G, I vs 1, O vs 0, H vs. X, 2 vs. Z

Figure 5 Twymans True Type Font for seven segment displays



3. Switches and DIP Switches

3.1 Introduction

DIP switches bundle multiple SPST switches together into a single component; “DIP” stands for “dual in-line package,” the standard IC package style that is breadboard compatible, and “SPST” means “single pole, single throw,” the simplest possible switch type. Figure 1 pictures two popular switches, a SPDT-, Single Pole, Double throw-slide-switch and a standard DIP switch containing eight SPST switches

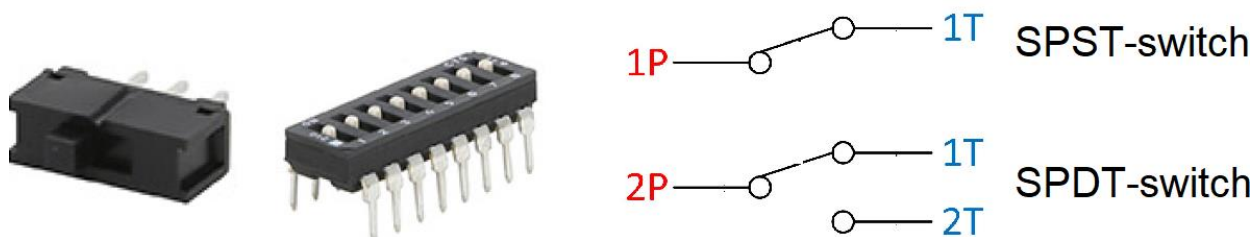


Figure 1: SPDT-switch and 8-position DIP-switch (8 times SPST)

3.2 Learning Objectives

After completing the activities in this chapter you will be able to:

- Describe the following concepts related to switches and the Innovator interface:
 - DIP switch bundles N SPST switches into a single component with each switch appearing as a short circuit in one position and as an open circuit in the other,
 - 2N-position rotary switch bundles N SPST switches into a single component; rotating the dial create a binary sequence of open-closed switch states. (figure 2, this switch is not included in the TI-Innovator Breadboard Kit).
- Interface a switch on any of the TI Innovator BB connectors without using additional components, and explainin the concept of pull up and pull down resistors

3. Interpret the combined switch open-closed patterns as an integer numerical value

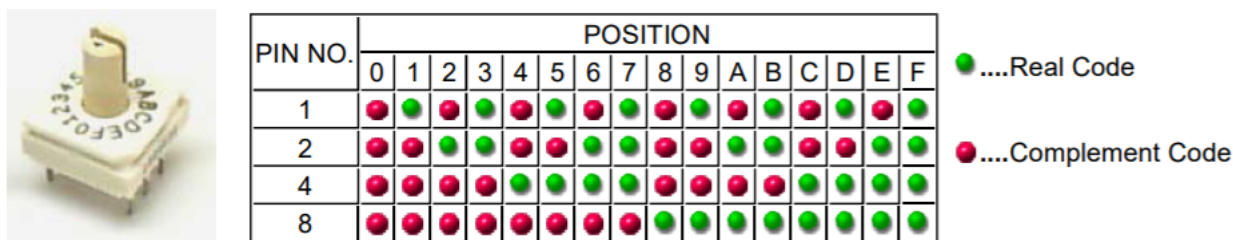


Figure 2 Rotary type DIP-Sitch with hexadecimal position code (not included in the Breadboard Pack)

3.3 Component Demonstration

Select these parts from the TI Innovator Breadboard Pack:

- SPDT Switch
- DIP switch
- Rotary DIP switch, not included => http://www.resonswitch.com/p_rs_rsr
- Breadboard
- Jumper wires
- Small screwdriver

Build the interface circuit: Refer to the schematic diagram shown in Figure 3

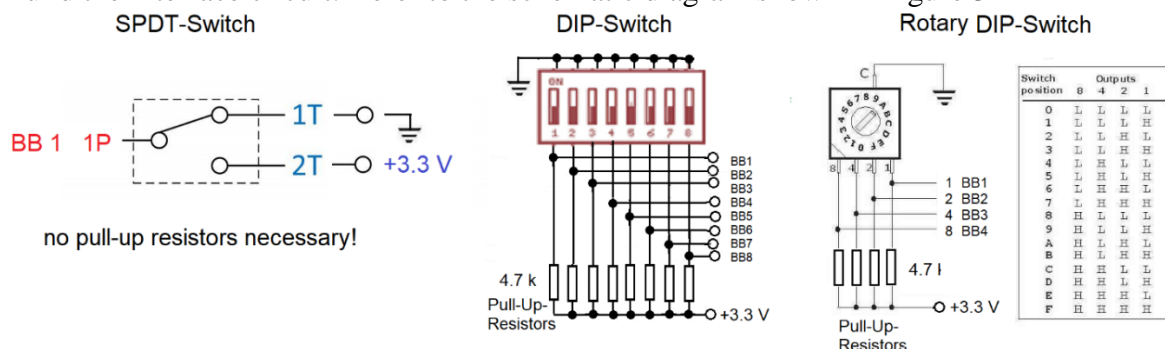


Figure 3 schematic diagrams for wiring three types of switches tot he TI-Innovator (BB1 to BB8)

Innovator Programs:

Define switch1()=

Prgm

Send "CONNECT SWITCH 1 TO BB1"

Send "READ SWITCH 1"

Get a

Disp a

EndPrgm

Define dipswitch()=

Prgm

For n,1,8

Send "CONNECT SWITCH eval(n) TO BB eval(n)"

Send "READ SWITCH eval(n)"

Get a

Disp a

EndFor

EndPrgm

Expected results:

The demo programs displays the individual switch states of the SPDT and the two DIP switches. An open switch appears as a low state. With the rotary DIP try clicking through the positions and observe the binary sequences, remembering that the switches appear active-high.

Try each of the eight switches on the DIP switch and confirm that you can individually activate the BB 1 to BB 8 states.

3.4 Interface Theory

Interface circuit: Each SPST switch in the standard DIP switch appears either as an open circuit or as a short circuit depending on the switch position “up” or “down.” The 16-position rotary switch opens all four SPST switches at Position 0 and then applies an ascending binary sequence to switch closings as the dial rotates clockwise.

3.5 More Information

2-Wire Controlled Digital DIP Switch by Maxim Integrated. An electronic replacement for mechanical DIP switches, the DS3904 contains microcontroller-controlled nonvolatile variable resistors that offer smaller footprint, higher reliability, and lower cost:

<http://www.maximintegrated.com/app-notes/index.mvp/id/238>

4. Relay, Diode MOS-FET Transistor**4.1 Introduction**

Low-power digital outputs lack the necessary current drive to operate motors, lights, and other high-current appliances.

Relays bridge the power gap using a relatively low-power magnetic coil to control a switch designed to carry large currents. Figure 1 shows at SPDT relay.

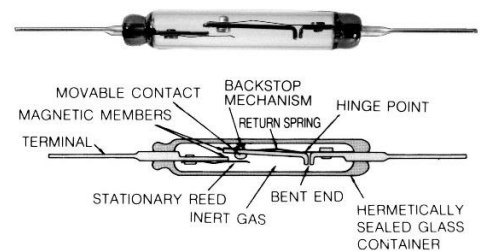


Figure 1: relay (left) and reed relay contact (right)
(not included in the innovators packs)

4.2 Learning Objectives

After completing the activities you will be able to:

1. Discuss the relay principles of operation,
2. Size the interface transistor to accommodate the relay coil current,
3. Explain why the rectifier is necessary to suppress back-emf voltage spiking when the transistor turns on and off,
4. Design the interface circuit to work.

4.3 Component Demonstration

Follow these steps to demonstrate correct operation of the relay.

Select these parts:

- 5 V DC Relay or 5 V DC Reed Relay

not included => www.digikey.com/products/en/relays/signal-relays-up-to-2-amps/189?k=relay

- general-purpose rectifier, e.g. 1N5819
- n-channel Power MOSFET CSD18504KCS
- Breadboard
- Jumper wires

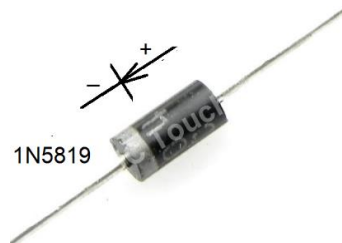


Figure 2 1N5819 40 V, 1A rectifier

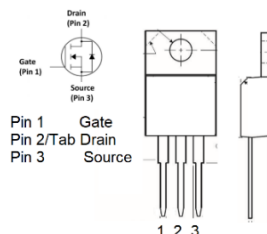


Figure 3 n-channel Power MOSFET CSD18504KCS

Build the interface circuit: Refer to the Figure 4.

Note that the three **relay switch contacts do not sit on tenth-inch centers** therefore this side of the relay must hang off the side of the breadboard.

The interface circuit requires three connections to TI Innovator B

1. 5-volt power supply
2. Ground
3. Relay control BB 1

Troubleshooting tips: Not seeing the expected results?
Confirm the following points:

- Correct transistor orientation and
- Correct rectifier orientation — when the rectifier is backwards the relay coil will never reach the voltage level necessary to turn on.

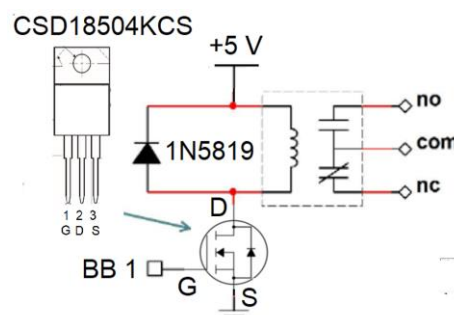


Figure 4 Demonstration circuit for relay

Innovator : 2 Program Samples

```
Define relay1()=
Prgm
Send "CONNECT LED 1 TO
BB 4"
For n,1,5
Send "SET LED 1
eval(255)"
WAIT 2
Send "SET LED 1 OFF"
WAIT 2
EndFor
Send " SET LED "
Send "DISCONNECT LED 1"
EndPrgm
```

```
Define relay1()=
Prgm
Send "CONNECT
ANALOG.OUT 1 1 TO BB 4"
For n,1,5
Send "SET
ANALOG.OUT 1 255"
WAIT 2
Send "ANALOG.OUT 1 0"
WAIT 2
EndFor
Send " SET LED "
Send "DISCONNECT
ANALOG.OUT 1"
EndPrgm
```

```
Define relay1()=
Prgm
Send "CONNECT
DIGITAL.OUT 1 1 TO BB 1"
For n,1,5
Send "SET DIGITAL.OUT 1
TO ON"
WAIT 2
Send " SET DIGITAL.OUT 1
TO OFF"
WAIT 2
EndFor
Send " SET LED "
Send "DISCONNECT
DIGITAL.OUT 1"
EndPrgm
```

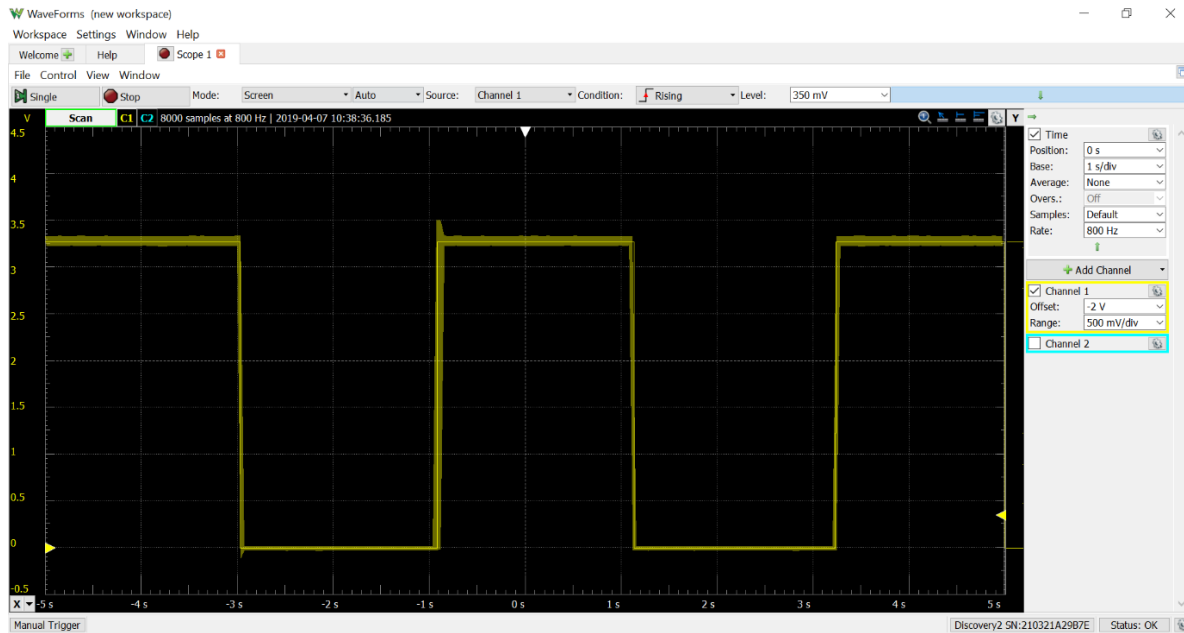


Figure 5 output voltage for the instructions « Send "SET LED 1 eval(255)" » , «Send "SET ANALOG.OUT 1 255"» or «SET DIGITAL.OUT 1 TO ON"» (Digilent Analog Discovery 2)

4.4 Interface Theory

The relay contains an electromagnet coil that operates a spring-loaded switch. The coil current is approximately 100 mA, well beyond the current drive limits of the TI Innovators output. The interface circuit uses a n-channel Power MOSFET as a switch to turn the coil current on and off and a rectifier to protect the transistor from large back-induced voltage when the transistor shuts off the coil current.

4.5 For More Information

Using Relays (Tips & Tricks) by Jumper One

Learn how to reduce relay switching time and minimize relay current for battery-powered applications: <http://jumperone.com/2011/10/using-relays>

5. Potentiometer

5.1 Introduction

A potentiometer is a three-terminal variable resistor. When connected to a power supply to form a voltage divider a potentiometer acts as a proportional rotation sensor. Figure 7.1 pictures a potentiometer (not included in Innovators bread-board pack).

5.2 Learning Objectives

After completing the activities in this chapter you will be able to:

1. Discuss how the potentiometer can be used as either one variable resistor or two series-connected complementary variable resistors,
2. Connect a potentiometer as a *voltage divider* to produce a voltage proportional to rotation angle, and
3. Select the potentiometer resistance to minimize power consumption and to minimize loading effects.



Figure 1 potentiometer.

5.3 Component Demonstration

Follow these steps to demonstrate correct operation of the potentiometer.

Select these parts:

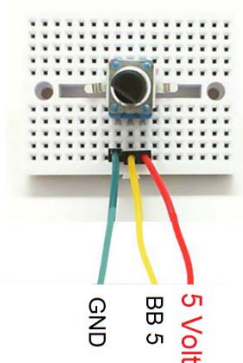
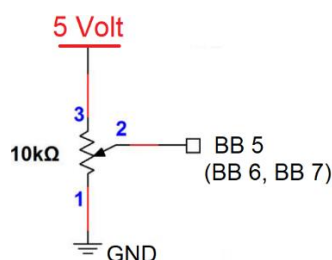
- Potentiometer, 10 k, not included
<http://www.supertech.com.tw/electronic/resistors/potentiometers/PDF/rotary3/23/R0904N.pdf>
- Breadboard
- Jumper wires

Build the interface circuit: Refer to the schematic diagram and recommended breadboard layout shown in Figure 5.2

TIP: Flatten the two tabs on either side of the potentiometer so that it sits flush on the breadboard surface.

The potentiometer interface circuit requires three connections to TI-Innovator

1. Pot Terminal 1 to BB GND
2. Pot Terminal 2 to BB 5 (analog input)
3. Pot Terminal 3 to BB 5 V



Innovator Program

```
Define potentiometer()=
Prgm
  Send "CONNECT POTENTIOMETER 1 TO BB 5 "
  Send "READ POTENTIOMETER 1 "
  Get p: Disp p
EndPrgm
```

Figure 2 program and demonstration circuit for potentiometer

Expected results:

The demo program displays the voltage on the analog input BB 5. 0 Volts => 00000, 3.3 Volt => 15'238, maximum value $16'384 \left(2^{14} - 1\right)$ corresponding to 3.55 Volt. Turn the potentiometer dial and you should observe a corresponding change in the voltage sensed on the analog input. Because the potentiometer acts as an adjustable voltage divider between ground and the +5-Volt supply, you should observe that a full rotation of the potentiometer dial from one extreme to the other causes the voltage to change from 0 to 5 volts.

5.4 Interface Theory

Interface circuit The potentiometer provides a fixed resistance between the two outer terminals, while the middle terminal connects to a movable contact point that effectively makes the potentiometer appear as two variable resistors. As one resistor increases in value, the other resistor decreases by the same amount. Wiring the potentiometer between ground and the power supply produces a voltage divider with voltage output proportional to the position of the contact. Connecting this variable voltage to the Innovator analog input BB 5-7 provides a convenient sensing technique for angular position.

5.5 For More Information

Potentiometer by Resistorguides Describes a variety of potentiometer types and characteristics:

<http://www.resistorguide.com/potentiometer>

6. Thermistor and TI analog Temperature Sensor

6.1 Introduction

The thermistor – a contraction of “thermal” and “resistor” – is a two-terminal semiconductor device whose resistance varies with temperature. Most thermistors are of the negative temperature coefficient (NTC) type, meaning their resistance varies inversely with temperature. Figure 1 pictures the TI Innovator breadboard kit thermistor.

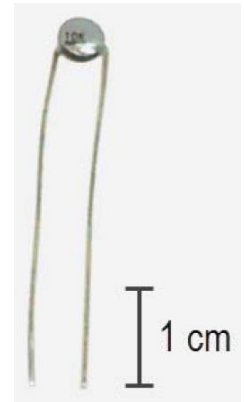


Figure 1 Innovator Breadboard Kit thermistor

6.2 Learning Objectives

After completing the activities in this chapter you will be able to:

1. Explain the thermistor principles of operation,
2. Measure the thermistor resistance a voltage divider and analog input,
3. Convert the measured resistance to temperature with the *Steinhart-Hart thermistor equation*, and
4. Size the voltage-divider resistor for the best measurement sensitivity and range.

6.3 Component Demonstration

Follow these steps to demonstrate correct operation of the thermistor.

Select these parts:

- Thermistor, 10 k, EPCOS B57164K103J, NTC-type
- Resistor, 10 k Ω
- Ceramic dis capacitor 104 0.1 μ F
- Breadboard
- Jumper wires

Build the interface circuit

Refer to the schematic diagram and recommended breadboard layout shown in Figure 2. The interface circuit requires four connections to TI Innovator

1. 5-volt power supply!B/+5V (pin 1)
2. Ground!B/GND (pin 6)
3. Temperature measurement BB 5 (analog input)
4. Supply voltage measurement BB 6 (analog input)

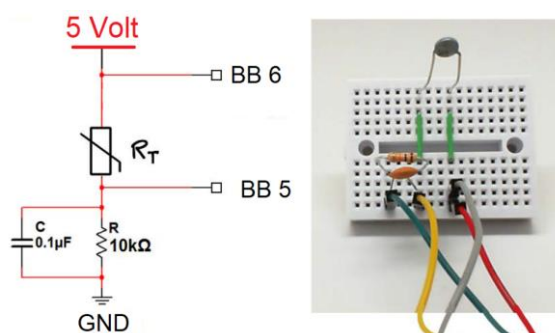


Figure 2 Demonstration circuit for thermistor

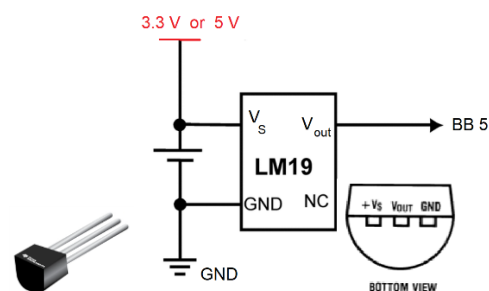


Figure 3 Temperature measurement with LM19 sensor (Texas Instruments)

Innovator Program

Define thermistor()=

Prgm

Send "CONNECT TEMPERATURE 1 TO BB 5 NTC"

Send "READ TEMPERATURE 1"

Get p: Disp p

Send "DISCONNECT TEMPERATURE 1"

EndPrgm

Expected results:

The program «thermistor» shows the temperature directly in degrees centigrade (Celsius). Refer to « TI Innovator technology handbook » for more information (e.g. calibration).

From a physical point of view it is more interesting to measure the thermistors voltage $U_{\text{Thermistor}}$, the supply voltage U_{Supply} and to calculate the resistance of the thermistor by

$$R_{\text{Thermistor}} = \frac{U_{\text{Thermistor}}}{I_{\text{Thermistor}}} = \frac{U_{\text{BB 6}} - U_{\text{BB 5}}}{\frac{U_{\text{BB 5}}}{R}} = R \cdot \left(\frac{U_{\text{BB 6}}}{U_{\text{BB 5}}} - 1 \right)$$

The exact resistance value of the $R = 10 \text{ k}\Omega$ -resistor has to be measured with an ohmmeter.

Expect to see a thermistor value close to $10 \text{ k}\Omega$ at room temperature, Try heating the thermistor by gently pinching the thermistor body with your finger tips; you may also use a drinking straw or hair dryer to blow warm air on the thermistor. You should observe the resistance going down. How low can you make the resistance? Use a plastic sandwich bag filled with two ice cubes or crushed ice. Surround the thermistor with ice and you should observe the resistance going up. How high can you make the resistance?

As an alternative it's a good idea to work with the LM19 sensor from Texas Instruments which needs no external components to work (Figure 3). The temperature range is from -55°C to 130°C . In a first approximation this sensor offers a quite good voltage (!) to temperature linearity (Figure 4); the approximation formula is (t Temperature in $^\circ\text{C}$, Voltage in Volts) :

$$V = -3.88 \cdot 10^{-6} \cdot t^2 - 1.15 \cdot 10^{-2} \cdot t + 1.8639 \quad \text{or}$$

$$t = -1481.96 + \sqrt{2.1962 \cdot 10^6 + \frac{1.8639 - V}{3.86 \cdot 10^{-6}}}$$

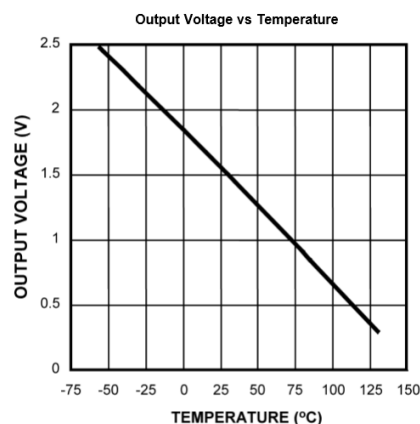


Figure 4 characteristic of the LM19 temperature sensor

Innovator Program for LM19

Define temperaturelm19()=

Prgm

Send "CONNECT POTENTIOMETER 1 TO BB 5"

Send "READ POTENTIOMETER 1"

Get a: Disp a

Send "DISCONNECT POTENTIOMETER 1"

EndPrgm

The measured voltage value appears as a 14-bit number between 0 and 16'383

6.3 Interface Theory

Constructing a voltage divider from a thermistor and a fixed-value resistor offers an effective and easy-to-build interface circuit. Placing the thermistor in the top branch of the divider makes the measured voltage increase with higher temperature. Learn more about thermistor characteristics and the Steinhart-Hart thermistor equation that converts measured thermistor resistance to temperature in degrees Kelvin (Figure 3).

Steinhart - Hart thermistor equation :

$$\frac{1}{T} = A + B(\ln R_T) + C(\ln R_T)^3$$

→ 3rd-order polynomial in $\ln R_T$,
omitting 2nd-order term

T = temperature in Kelvin (K)
 R_T = thermistor resistance in ohms

→ calculates temperature from
measured thermistor resistance

Figure 4 Steinhart-Hart thermistor equation

6.5 For More Information

- Thermistors by National Instruments thermistor characteristics and the Steinhart-Hart thermistor equation: <http://zone.ni.com/reference/en-XX/help/370466V-01/measfunds/thermistors>
- NTC Thermistors by Vishay. Learn about thermistor principles of operation, selection criteria, design equations, and example circuits and applications: <http://www.vishay.com/docs/29053/ntcintro.pdf>

7. Conclusions

It's a good idea to replace the old fashion boring electric student labs with bulbs, primitive switches, bad connectors, wires, batteries etc. by up to date microcontroller operated circuits with modern components, switches, breadboards, jumper wires and so on. By introducing up to date technology instruction the physics education benefits from the enormous technical progress of the semiconductor based microelectronics in the last decades. A way to explain some aspects of the today digital world to our students. They learn basic electricity and electronic concepts in a field between physics and technology. What is a switch, a LED, a display, a potentiometer, a diode, a transistor etc. How work these components and how are they wired in the hardware circuit? The list of possible components can be completed with a lot of other sensors, photo-cells, microphones, motors, buzzers, speakers, photoelectric and Hall sensors etc. The new approach : All these components are microcontroller driven. Under the many existing microcontroller systems the Innovator System is a good choice also if it is not the cheapest one. It has a professional design and can be operated by a simple programming language (Basic) from Computers or handheld calculators.