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DAY 3 : Understanding Analog to Digital Converters

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Don Wilcher

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Agenda:

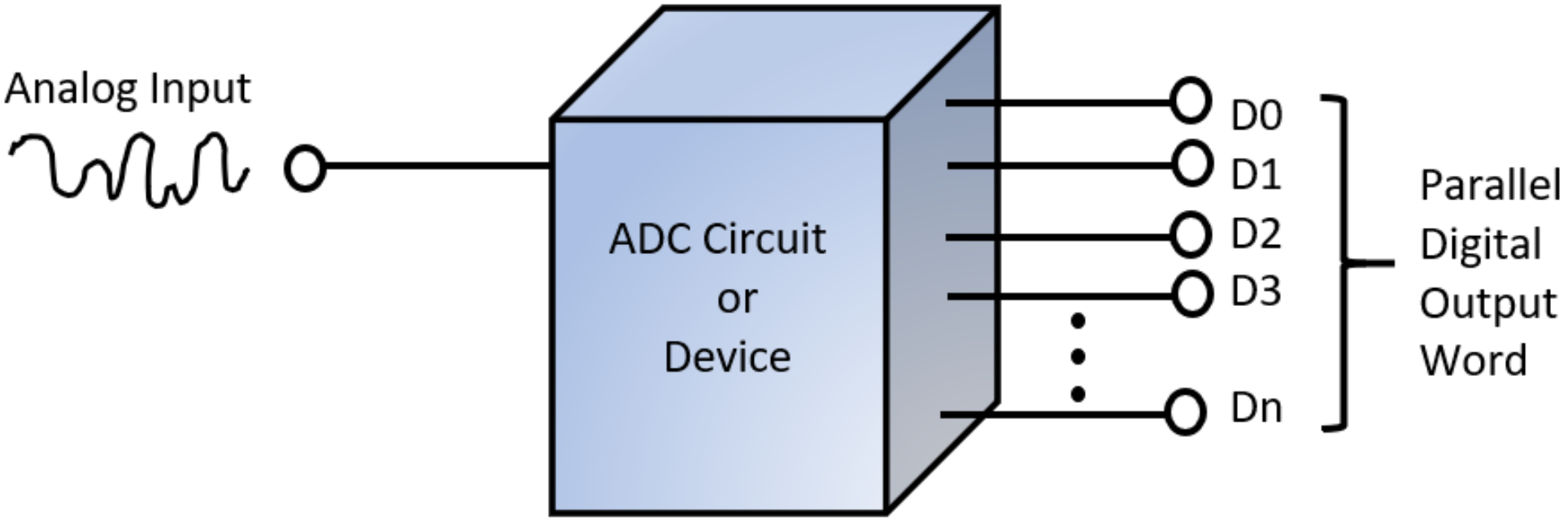
- What is an Analog to Digital Converter
- The PCF8951 Analog to Digital Converter
- Lab: A 3VDC Voltmeter

What is an Analog to Digital Converter?

- A circuit that converts continuous analog voltage to a 2-state digital signal
- The digital output value or frequency of the converter is always proportional to the analog input value.
- The weight of the output word is proportional to the analog input level
- The digital output lines of the converter are combined to form a parallel output word.
- Greater conversion resolution can be obtained by increasing the number of output lines or bits of the converter.

What is an Analog to Digital Converter?...

A typical Analog to Digital Converter (ADC) or Device



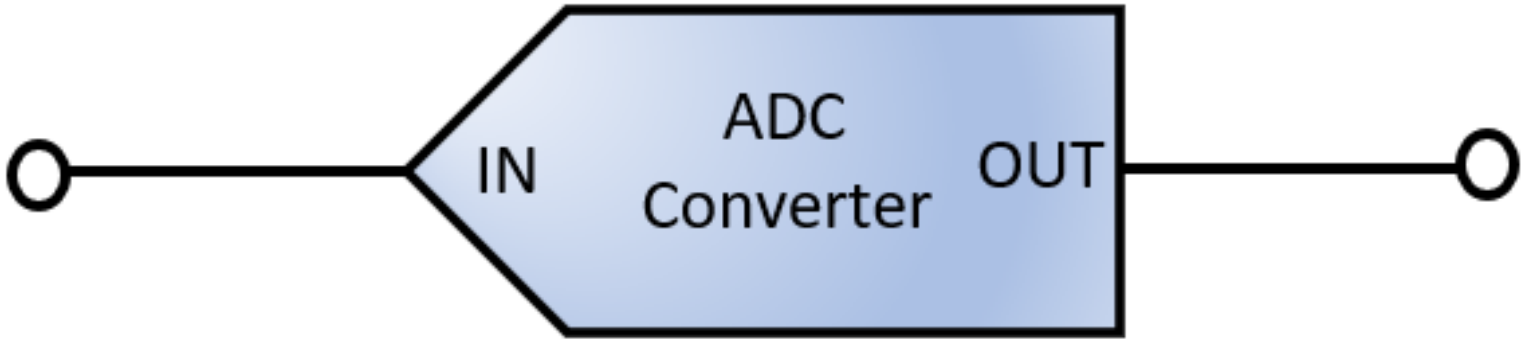
Weight of the output word is proportional to analog input level

Question 1

The digital output value or frequency of an ADC is always_____ to the analog input value.

What is an Analog to Digital Converter?...

The ADC Electronic Symbol



What is an Analog to Digital Converter?...

Determining the ADC Voltage of an Analog Signal Analysis Equations

Equation 1: Step Size Voltage = Vsupply/ADC Bit size

Equation 2: Vout = Weighted Value x Step Size Voltage

Equation 3: ADC Bit size = 2^n, where n = number of bits

Example:
Determine the Step Size Voltage and of an 8Bit ADC with a supply voltage of 5VDC. Also, calculate the output voltage at Bit 2 of the ADC.

ADC Bit size = 2^n
ADC Bit size = 2^8 = 256

Step Size Voltage = Vsupply/ADC Bit size
= 5VDC/ 256
= 0.0195V or 19.5mV

What is an Analog to Digital Converter?...

Determining the ADC Voltage of an Analog Signal Analysis Equations…

Equation 2: Vout = Weighted Value x Step Size Voltage

Equation 4: Weight Value = 2^n where n = Bit position
At Bit position 2:

Weighted Value = 2^n
= 2^ 2
= 4
Vout = Weighted Value x Step Size Value
= 4 x 0.0195V
= 0.078V

What is an Analog to Digital Converter?...

5V/256 = 0.0195V or 19.5mV

Our 8-bit converter represents the analog input as a digital word. The most significant bit of this word indicates whether the input voltage is greater than half the reference (2.5V, with a 5V reference). Each succeeding bit represents half the range of the previous bit.

Table 1 Example conversion, on an 8-bit ADC

Bit:	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Volts:	2.5	1.25	0.625	0.3125	0.156	0.078	0.039	0.0195
Output Value:	0	0	1	0	1	1	0	0

Table 1 illustrates this point. Adding the voltages corresponding to each set bit in 0010 1100, we get:

.625 + .156 + .078 = .859 volts

Source:

Ball, S. (2001). *Analog to Digital Converters.* Retrieved from https://www.eetimes.com/analog-to-digital-converters/#

Question 2

Using the ADC signal analysis equation procedure shown on slide 9, determine the step size voltage with a 3.3VDC supply.

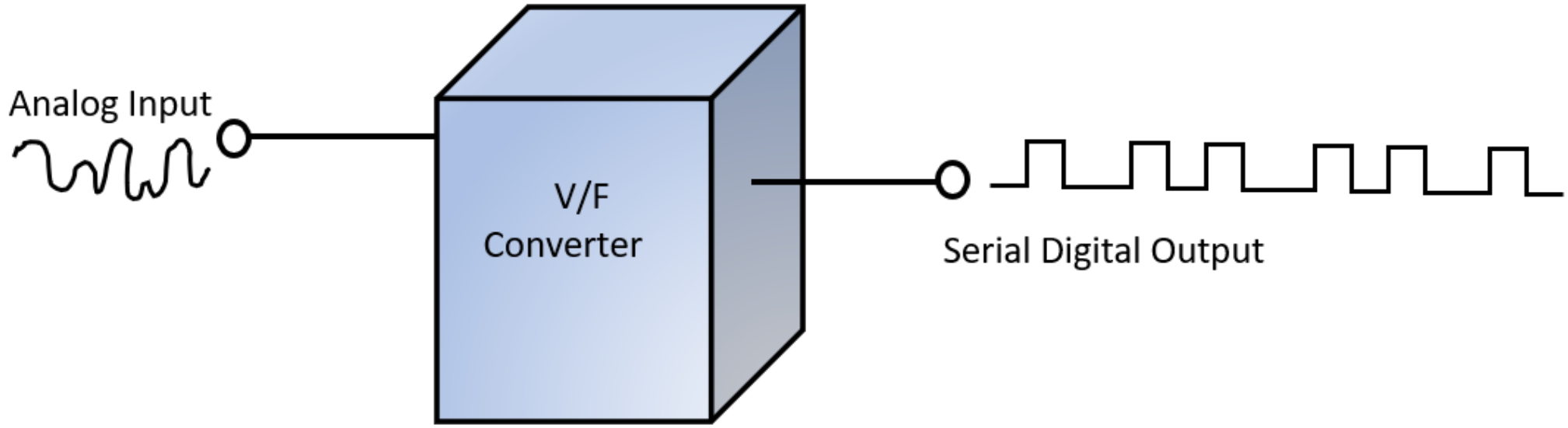
What is an Analog to Digital Converter?...

Voltage to Frequency (V/F) Converter

- Another type of ADC device
- Converts an analog input signal and converts it to a series of output pulses.
- The rate of the digital output pulses generated are proportional to the analog input voltage level.
- The digital output frequency of the V/F converter is proportional to the analog input voltage level.
- Although the industry refers to the serial output device as V/F converter and not an ADC, it is an ADC.

What is an Analog to Digital Converter?...

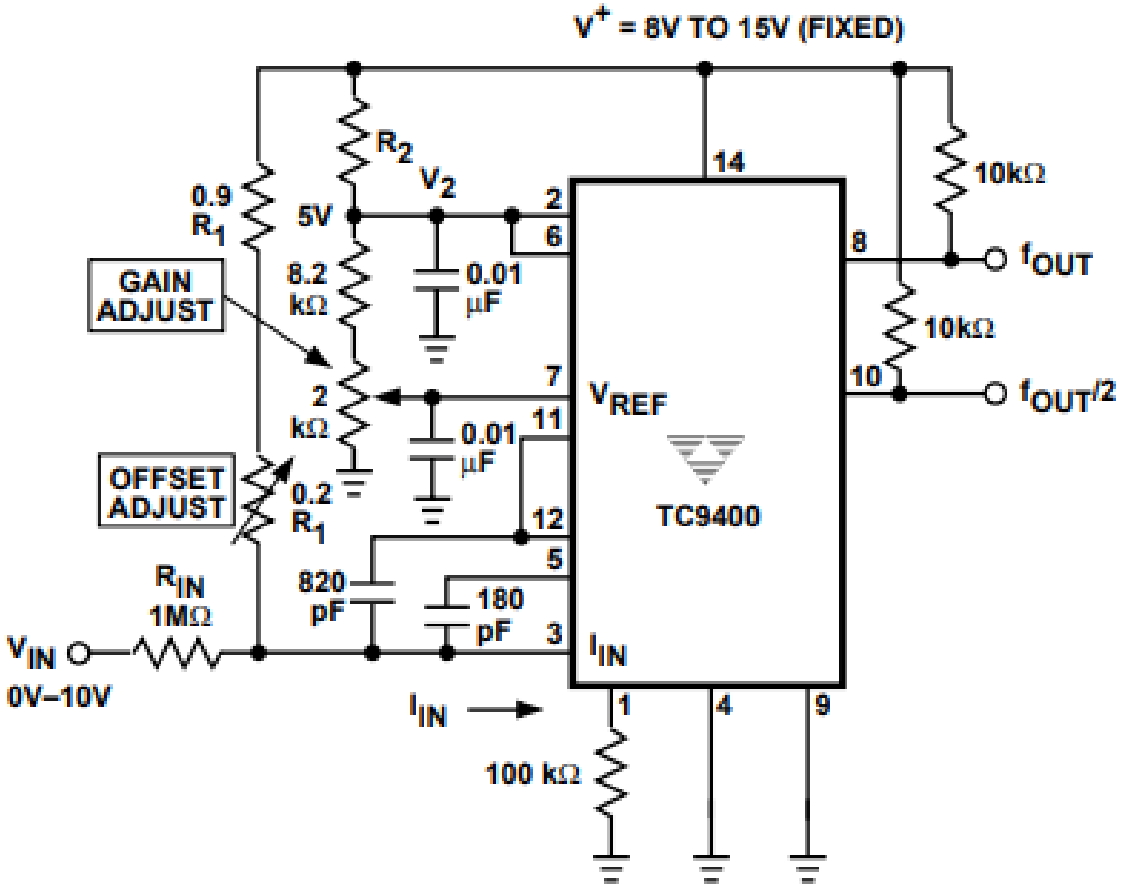
Voltage to Frequency (V/F) Converter



The rate of the digital output pulses generated are proportional to the analog input voltage level.

What is an Analog to Digital Converter?...

Voltage to Frequency (V/F) Converter



Source:
http://www.farnell.com/datasheets/32473.pdf

What is an Analog to Digital Converter?...

Voltage to Frequency (V/F) Converter

Partial Datasheet

TelCom Semiconductor, Inc.

TC9400
TC9401
TC9402

VOLTAGE-TO-FREQUENCY/FREQUENCY-TO-VOLTAGE CONVERTERS

FEATURES

Voltage-to-Frequency

- Choice of Guaranteed Linearity:
  - TC9401 ..... 0.01%
  - TC9400 ..... 0.05%
  - TC9402 ..... 0.25%
- DC to 100 kHz (F/V) or 1Hz to 100kHz (V/F)
- Low Power Dissipation ..... 27mW Typ
- Single/Dual Supply Operation ..... + 8V to + 15V or ±4V to ±7.5V
- Gain Temperature Stability ..... ±25 ppm/°C Typ.
- Programmable Scale Factor

Frequency-to-Voltage

- Operation ..... DC to 100kHz
- Choice of Guaranteed Linearity:
  - TC9401 ..... 0.02%
  - TC9400 ..... 0.05%
  - TC9402 ..... 0.25%
- Programmable Scale Factor

APPLICATIONS

- µP Data Acquisition
- 13-Bit Analog-to-Digital Converters
- Analog Data Transmission and Recording
- Phase-Locked Loops
- Frequency Meters/Tachometer
- Motor Control
- FM Demodulation

GENERAL DESCRIPTION

The TC9400/TC9401/TC9402 are low-cost voltage-to-frequency (V/F) converters utilizing low power CMOS technology. The converters accept a variable analog input signal and generate an output pulse train whose frequency is linearly proportional to the input voltage.

The devices can also be used as highly-accurate frequency-to-voltage (F/V) converters, accepting virtually any input frequency waveform and providing a linearly-proportional voltage output.

A complete V/F or F/V system only requires the addition of two capacitors, three resistors, and reference voltage.

ORDERING INFORMATION

Part No.	Linearity (V/F)	Package	Temperature Range
TC9400COD	0.05%	14-Pin SOIC (Narrow)	0°C to +70°C
TC9400CPD	0.05%	14-Pin Plastic DIP	0°C to +70°C
TC9400EJD	0.05%	14-Pin CerDIP	– 40°C to +85°C
TC9401CPD	0.01%	14-Pin Plastic DIP	0°C to +70°C
TC9401EJD	0.01%	14-Pin CerDIP	– 40°C to +85°C
TC9402CPD	0.25%	14-Pin Plastic DIP	0°C to +70°C
TC9402EJD	0.25%	14-Pin CerDIP	– 40°C to +85°C

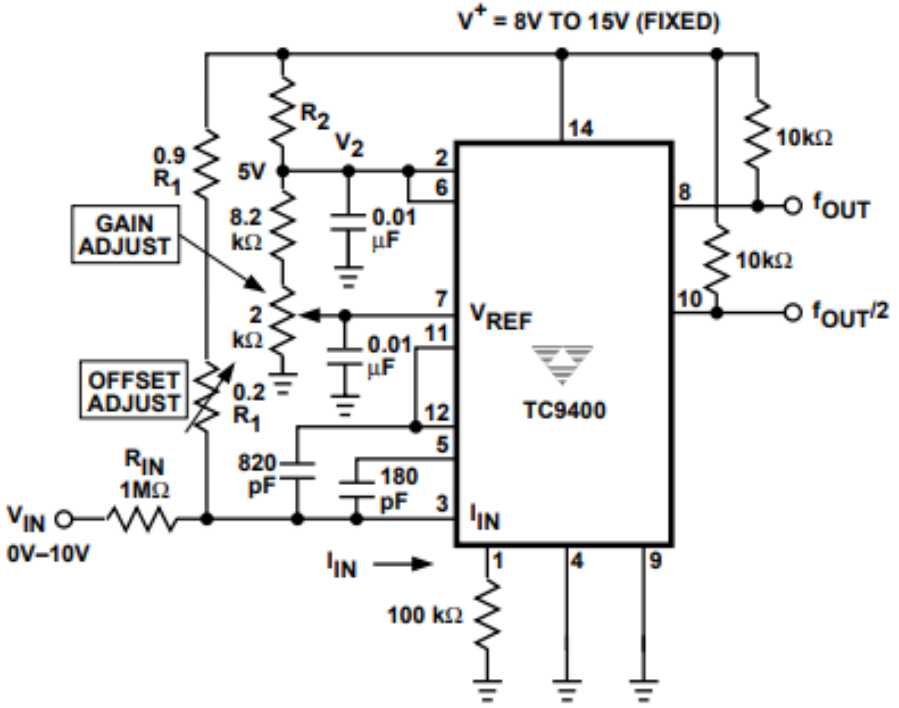
What is an Analog to Digital Converter?...

Voltage to Frequency (V/F) Converter:

Example:
Determine the output frequency (fout) for the TC9400 V/F Converter with the following circuit parameters.

Rin = 1MΩ
Vin = 5VDC
Cref = 180pF
Vref = 5VDC

Solution:
fout = Vin / (RinCrefVref)
= 5VDC / (1MΩ x180pF x 5VDC)
= 5.56KHz



Source:
http://www.farnell.com/datasheets/32473.pdf

PCF8951 Analog to Digital Converter

1. General description

The PCF8591 is a single-chip, single-supply low-power 8-bit CMOS data acquisition device with four analog inputs, one analog output and a serial I^2C-bus interface. Three address pins A0, A1 and A2 are used for programming the hardware address, allowing the use of up to eight devices connected to the I^2C-bus without additional hardware. Address, control and data to and from the device are transferred serially via the two-line bidirectional I^2C-bus.

The functions of the device include analog input multiplexing, on-chip track and hold function, 8-bit analog-to-digital conversion and an 8-bit digital-to-analog conversion. The maximum conversion rate is given by the maximum speed of the I^2C-bus.

Source:

https://www.nxp.com/docs/en/data-sheet/PCF8591.pdf

PCF8951 Analog to Digital Converter…

2. Features and benefits

- Single power supply
- Operating supply voltage 2.5 V to 6.0 V
- Low standby current
- Serial input and output via I^2C-bus
- I^2C address selection by 3 hardware address pins
- Max sampling rate given by I^2C-bus speed
- 4 analog inputs configurable as single ended or differential inputs
- Auto-incremented channel selection
- Analog voltage range from V_{SS} to V_{DD}
- On-chip track and hold circuit
- 8-bit successive approximation A/D conversion
- Multiplying DAC with one analog output.

Source:

https://www.nxp.com/docs/en/data-sheet/PCF8591.pdf

Question 3

Determine fout for a TC9400 V/F converter using the following circuit parameters.

Rin = 1MΩ

Vin = 3VDC

Cref = 100pF

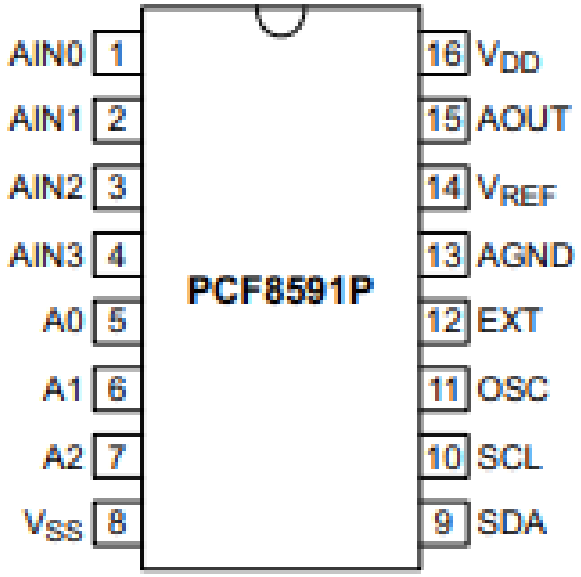
Vref = 2.5VDC

PCF8951 Analog to Digital Converter…

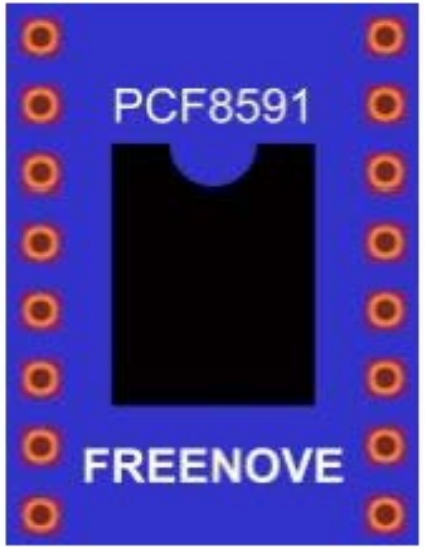
3. Applications

- Supply monitoring
- Reference setting
- Analog control loops

IC Pinout



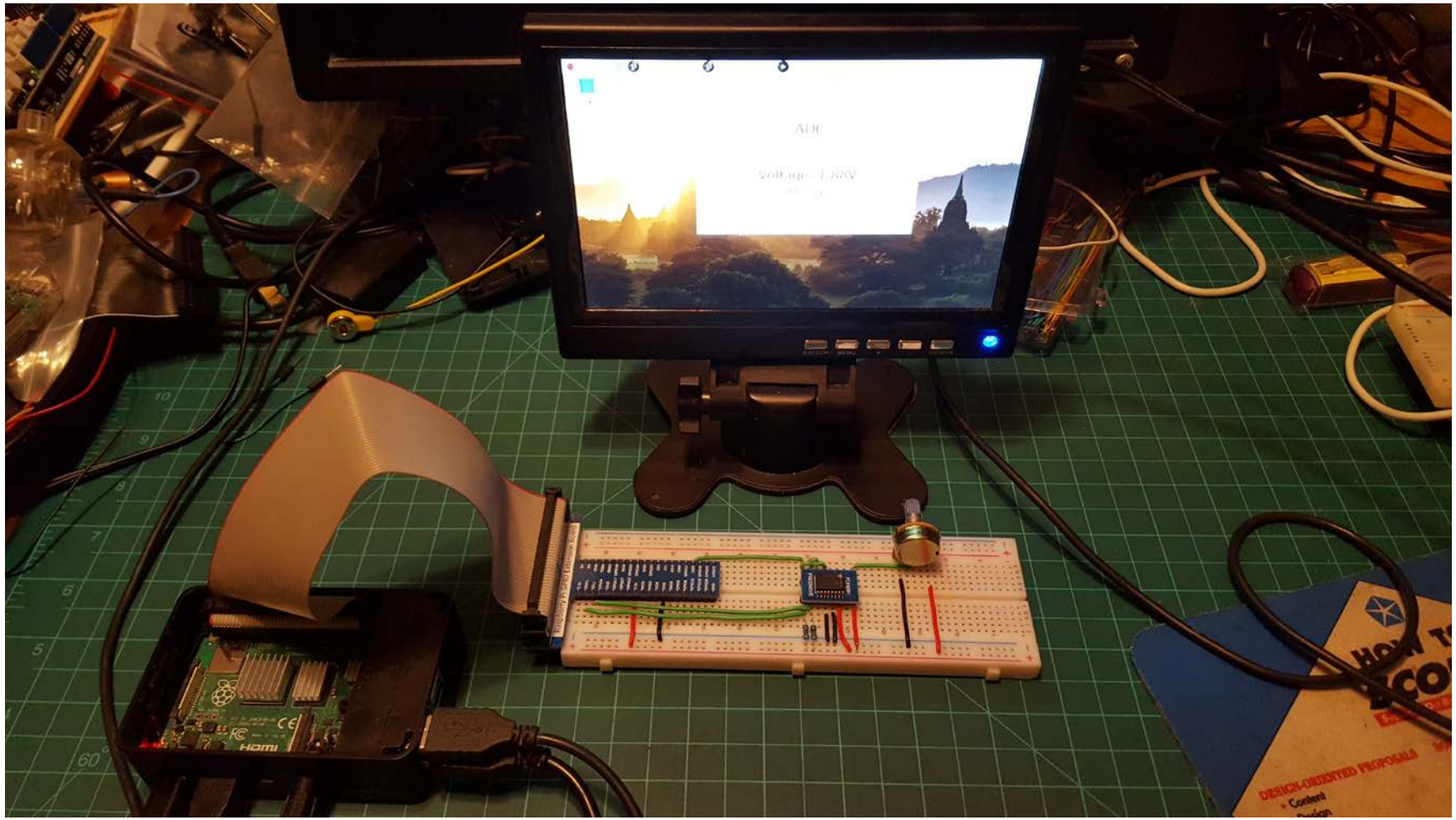
Module



Source:

https://www.nxp.com/docs/en/data-sheet/PCF8591.pdf

Lab Project: A 3VDC Voltmeter



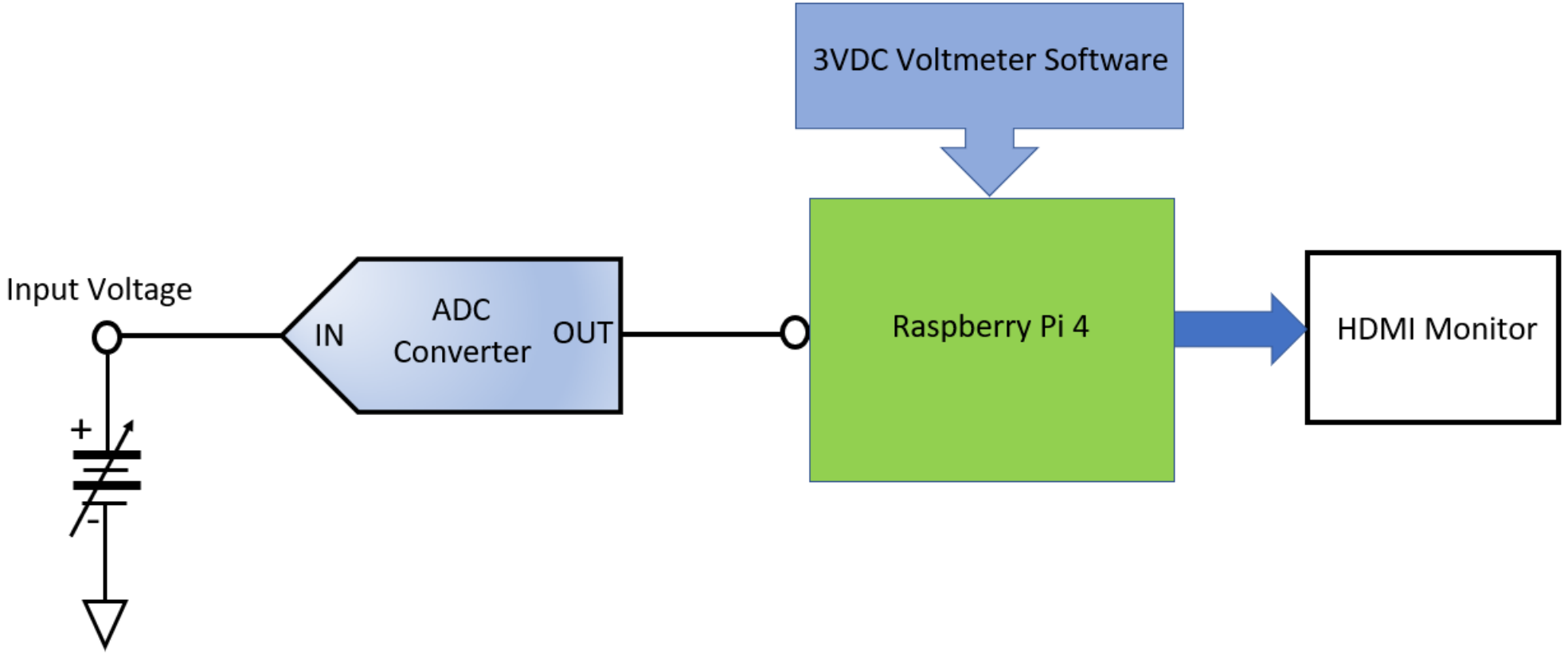
Lab Project: A 3VDC Voltmeter

Big IDEAS:

1. Learners will be able to wire a measuring device using a few off the shelf components .
2. Learners will be able to build a sensing device using Physical Computing concepts.
3. Learners will be able to make small changes to the code for personalization.

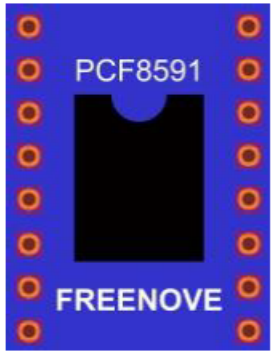
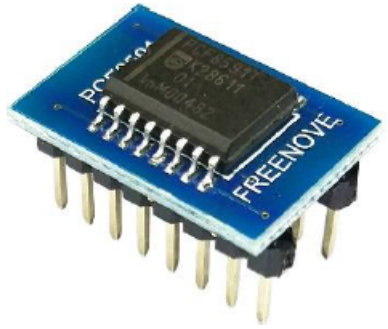
Lab Project: A 3VDC Voltmeter…

3VDC Voltmeter Block Diagram



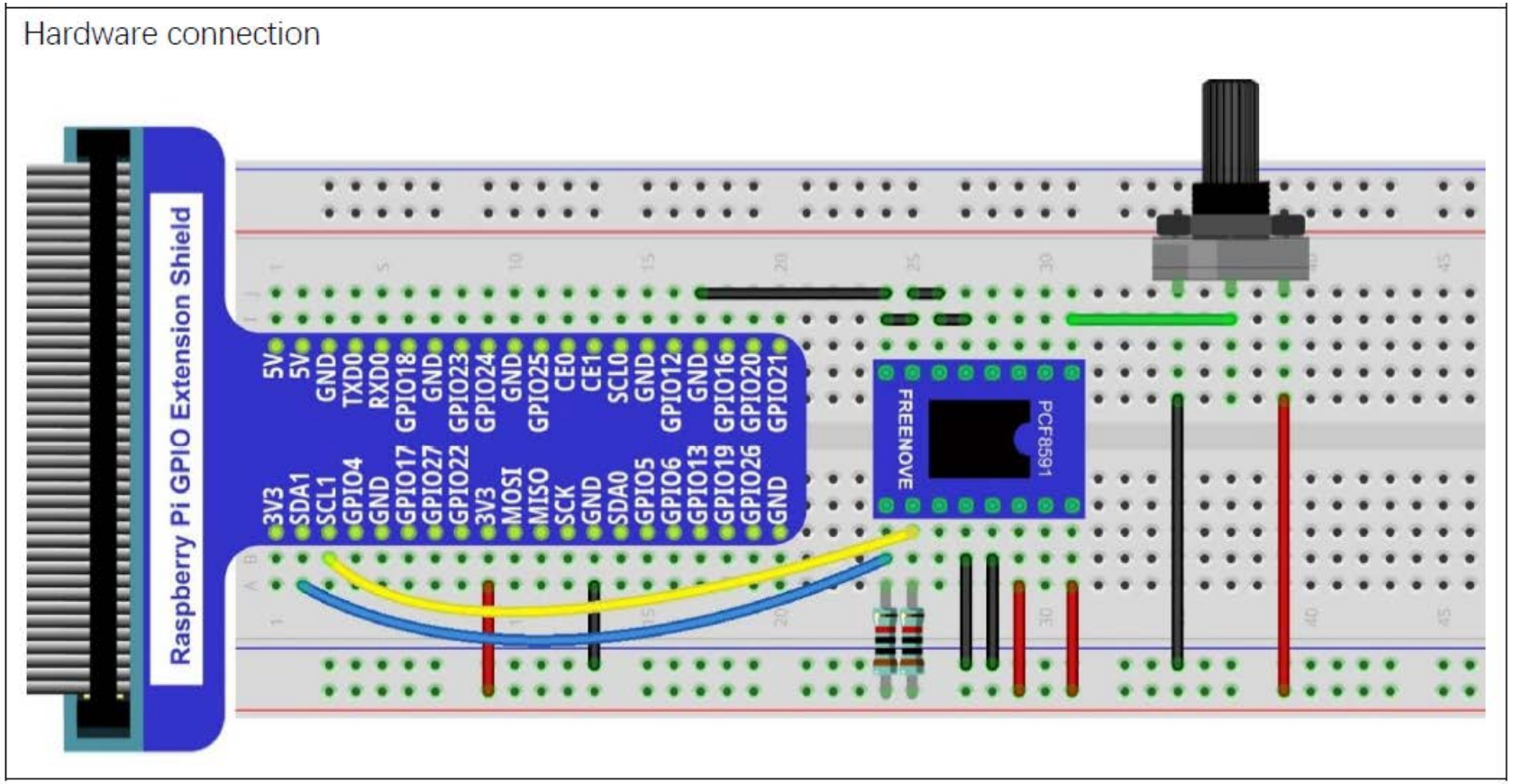
Lab Project: A 3VDC Voltmeter…

Major Components

ADC module : PCF8591		Resistor 10kΩ x2
		

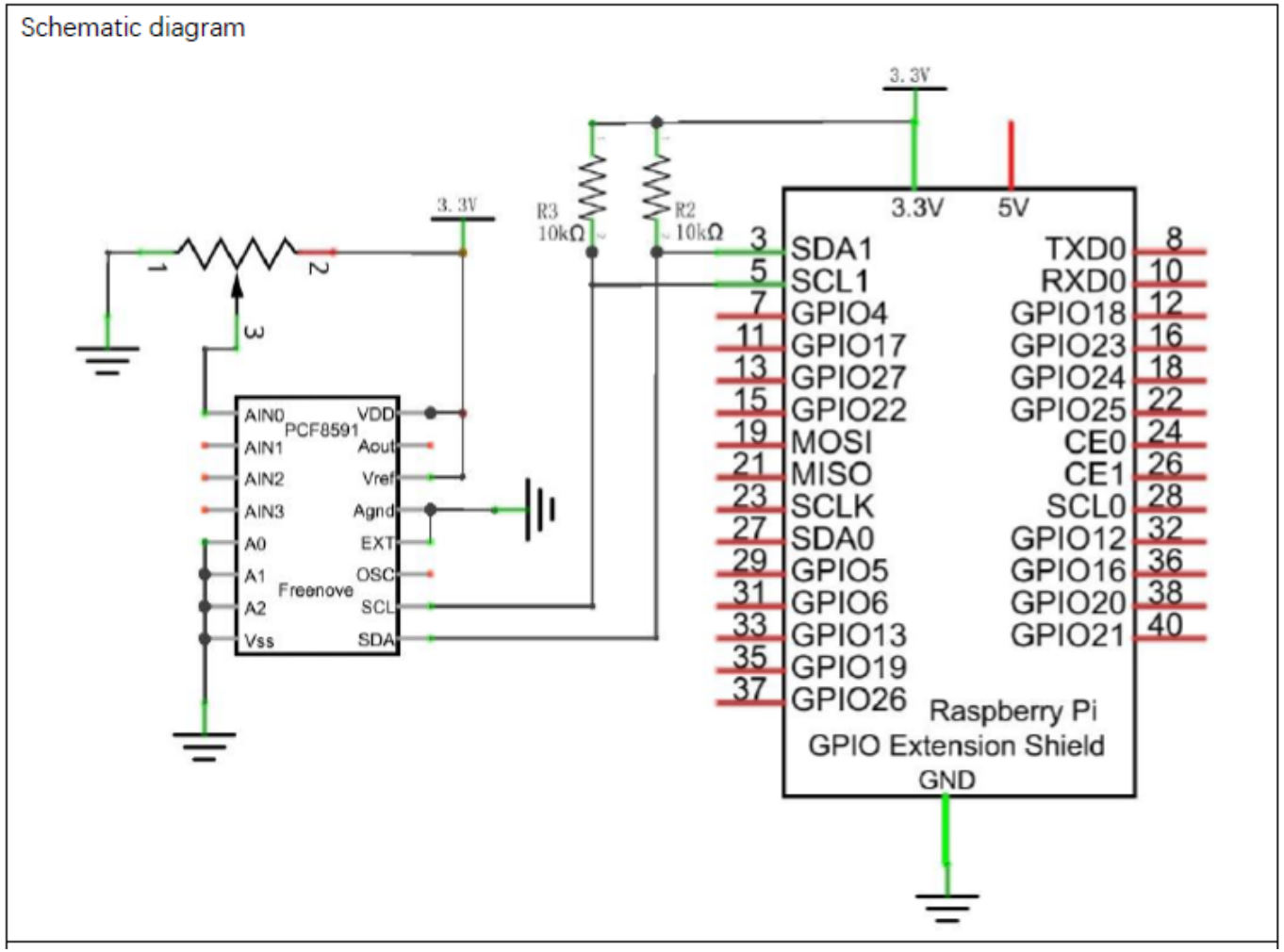
Lab Project: A 3VDC Voltmeter…

Electrical Wiring Diagram



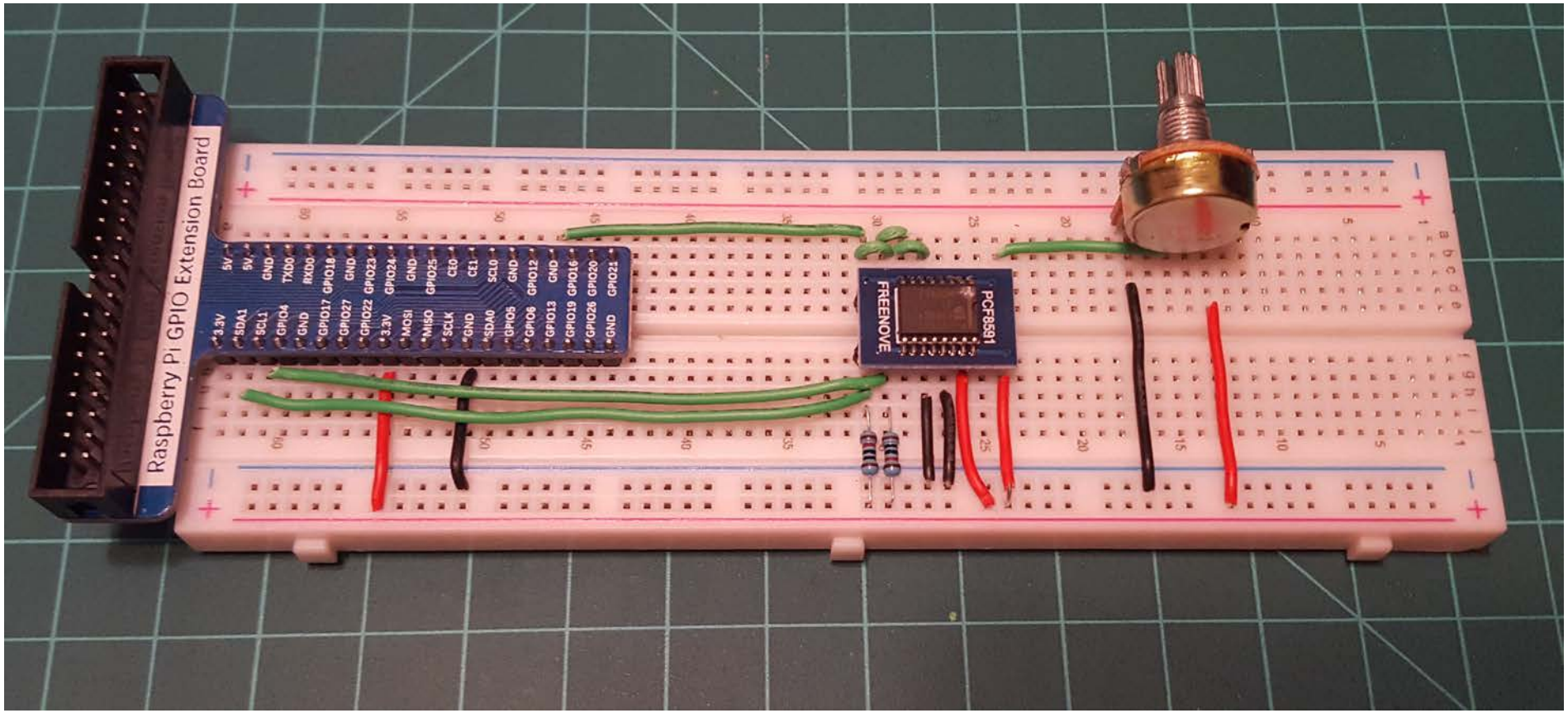
Lab Project: A 3VDC Voltmeter…

Electronic Circuit Schematic Diagram



Lab Project: A 3VDC Voltmeter…

Circuit Breadboard Complete



Question 4

Besides using a potentiometer to interact with the PCF8951 ADC, name another sensory component.

Lab Project: A 3VDC Voltmeter…

Processing Code

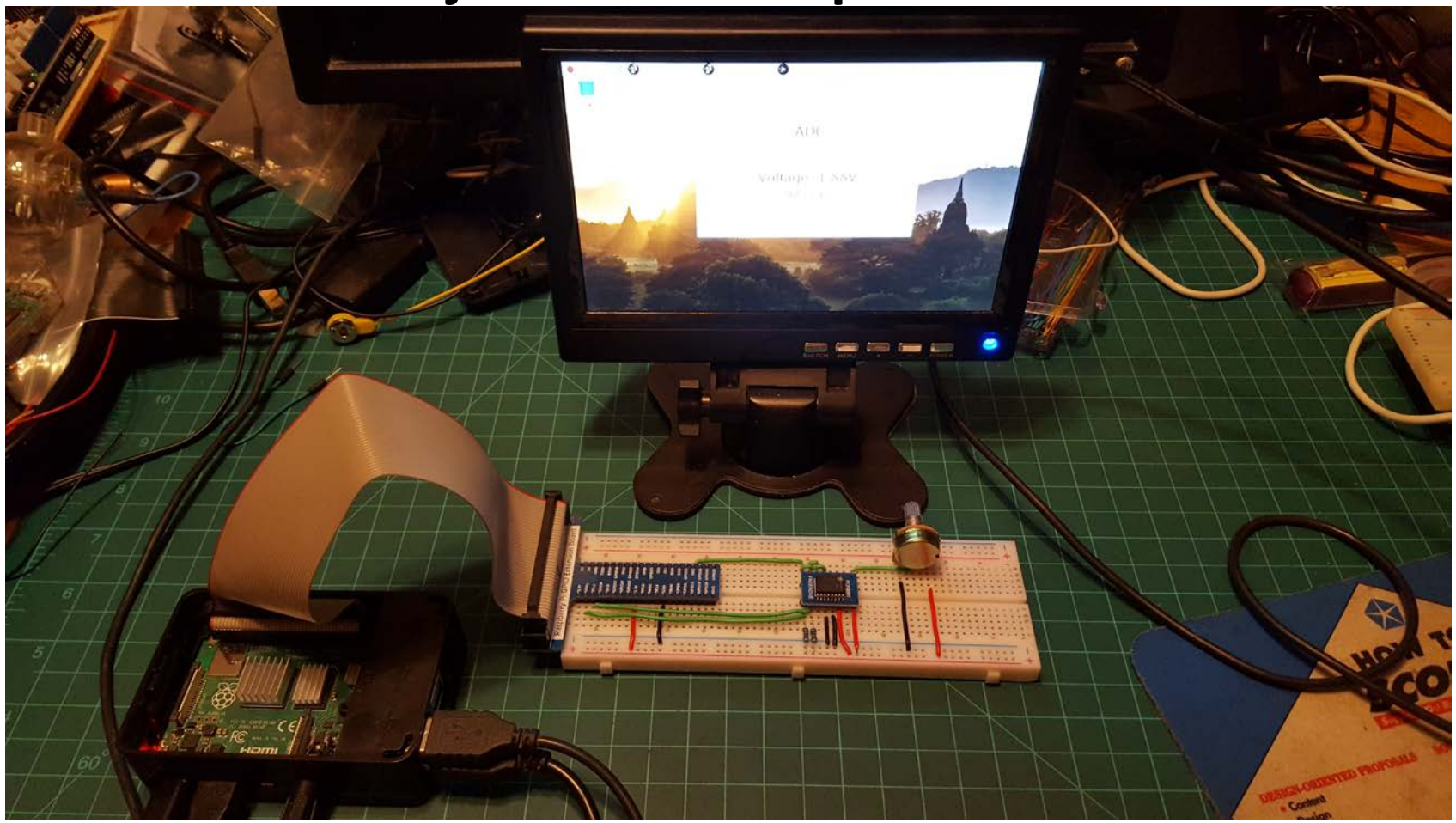
```
1   import processing.io.*;
2   //Create a object of class ADCDevice
3   ADCDevice adc = new ADCDevice();
4   void setup() {
5     size(640, 360);
6     if (adc.detectI2C(0x48)) {
7       adc = new PCF8591(0x48);
8     } else if (adc.detectI2C(0x4b)) {
9       adc = new ADS7830(0x4b);
10    } else {
11      println("Not found ADC Module!");
12      System.exit(-1);
13    }
14  }
```

Lab Project: A 3VDC Voltmeter…

Processing Code…

```
15  void draw() {
16    int adcValue = adc.analogRead(0);    //Read the ADC value of channel 0
17    float volt = adcValue*3.3/255.0;    //calculate the voltage
18    background(255);
19    titleAndSiteInfo();
20
21    fill(0);
22    textAlign(CENTER);    //set the text centered
23    textSize(30);
24    text("ADC: "+nf(adcValue, 3, 0), width / 2, height/2+50);
25    textSize(40);        //set text size
26    text("Voltage: "+nf(volt, 0, 2)+"V", width / 2, height/2);    //
27  }
28  void titleAndSiteInfo() {
29    fill(0);
30    textAlign(CENTER);    //set the text centered
31    textSize(40);        //set text size
32    text("ADC", width / 2, 40);    //title
33    textSize(16);
34    text("www.freenove.com", width / 2, height - 20);    //site
35  }
```

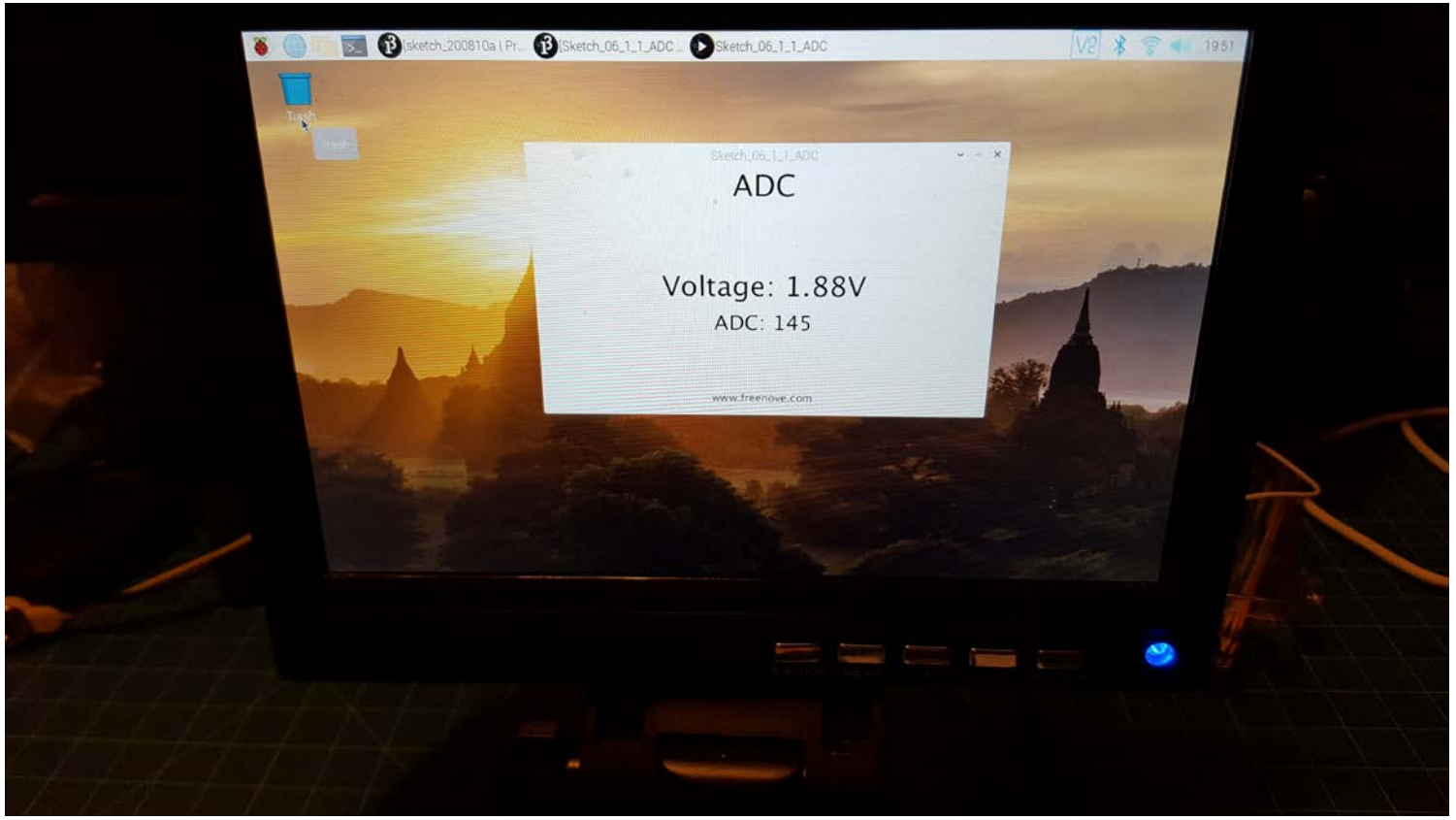
Lab Project: A 3VDC Voltmeter…
Project Build Complete



Lab Project: A 3VDC Voltmeter…

Output of 3VDC Voltmeter

Demo

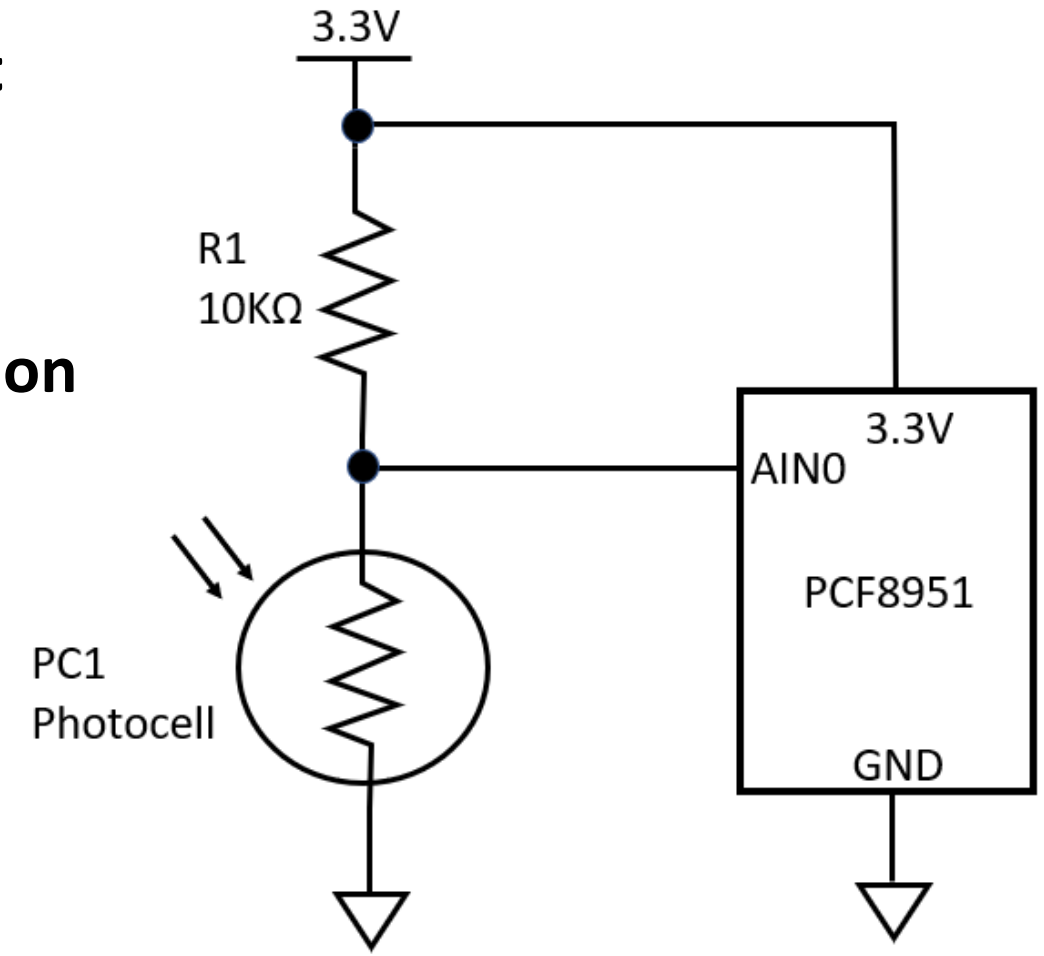


https://youtu.be/1m5-Sm0U5n0

Bonus Lab Project: A Light Meter

10KΩ Potentiometer replaced with a light detection circuit

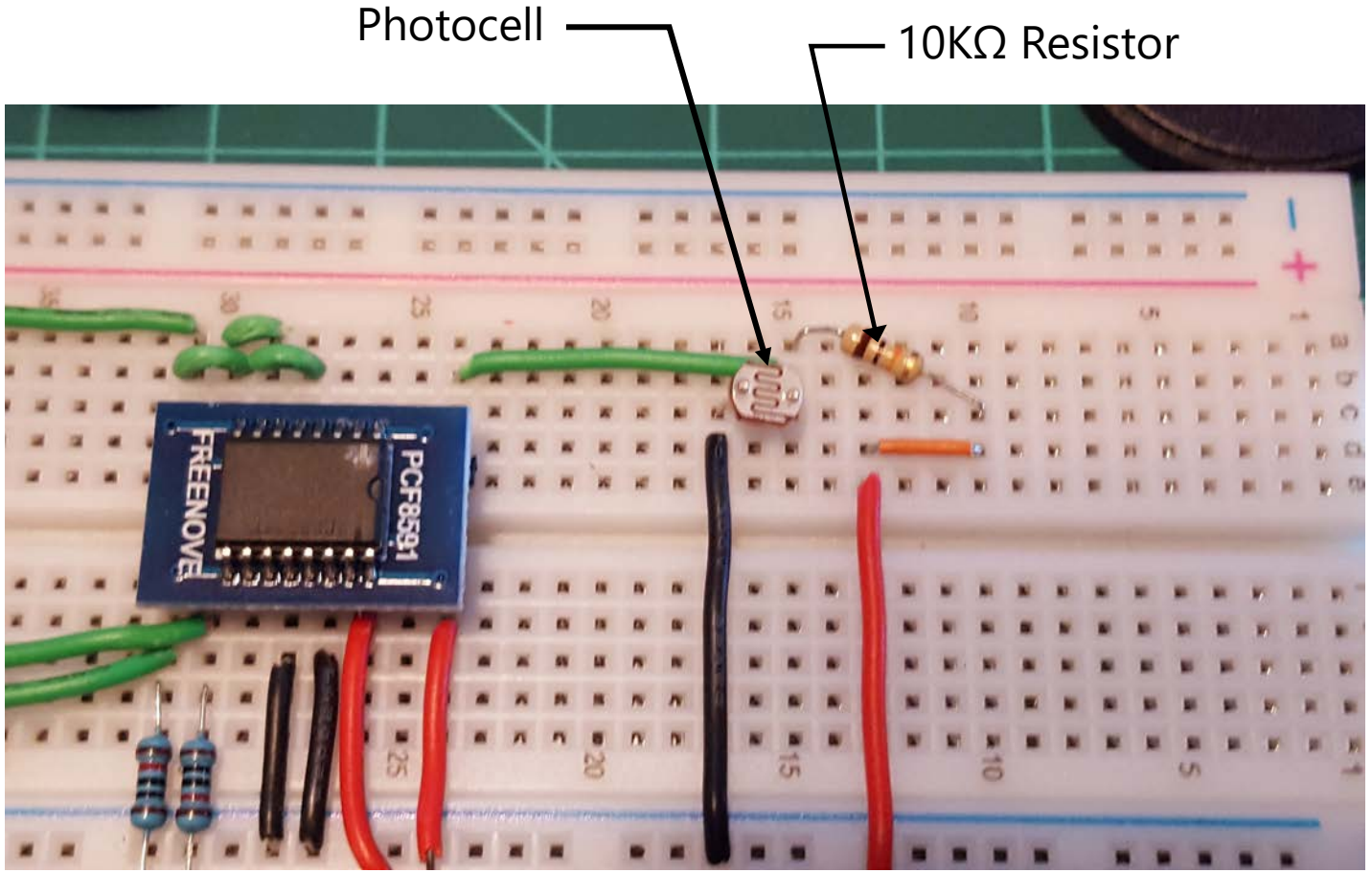
Light Detection Circuit



Bonus Lab Project: A Light Meter Modified Circuit Breadboard

Demo

https://youtu.be/2-MOiO9nGEk



Question 5

In reviewing the Processing code for the 3VDC Voltmeter, write down the equation that calculates the voltage.

Thank you for attending

Please consider the resources below:

- Analog to Digital Converters

  Ball, S. (2001). *Analog to Digital Converters.* Retrieved from https://www.eetimes.com/analog-to-digital-converters/#

- Physical Computing

  O'Sullivan, D., & Igoe, T. (2004). *Physical computing: Sensing and controlling the physical world with computers*. Boston, MA: Thompson.

- Telecom Semiconductor TC9400 Datasheet

  http://www.farnell.com/datasheets/32473.pdf

- Freenove Ultimate Starter Kit for Raspberry Pi

  http://www.freenove.com/tutorial.html

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