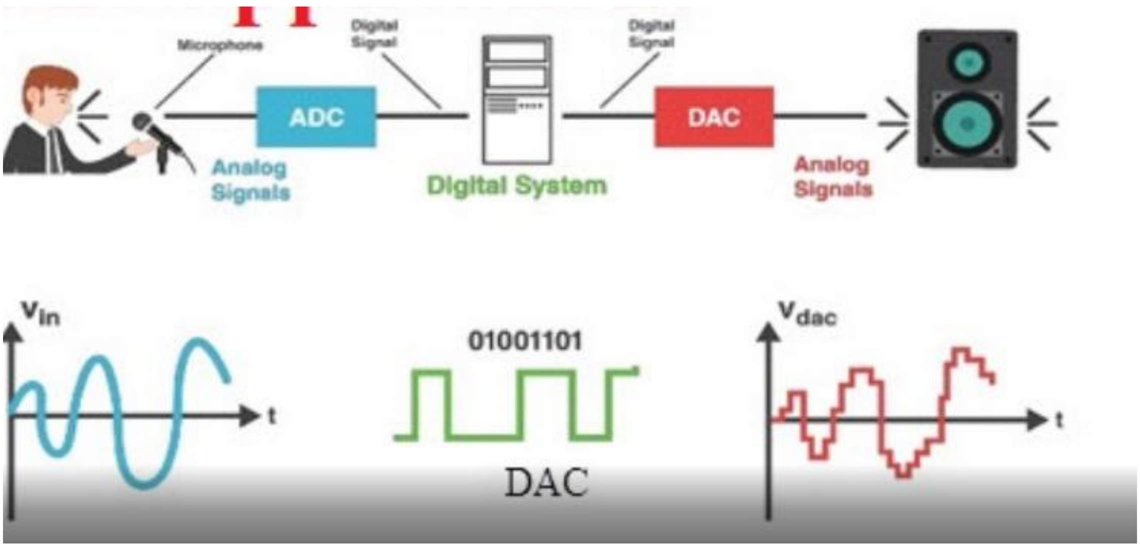
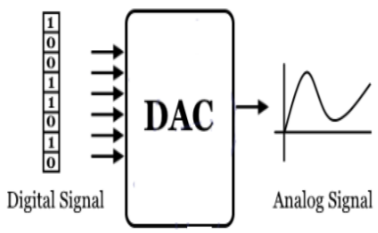
DIGITAL TO ANALOG CONVERTER (DAC)

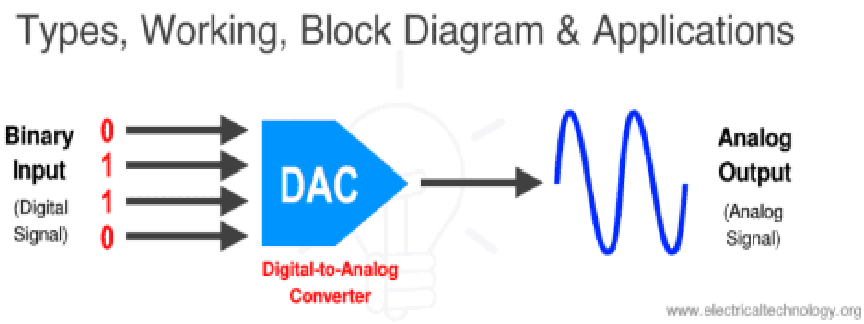


Introduction : The signals are two types i.e. Analog & Digital signal. The information that is in real world exists in analog form, while the digital devices can only understand the digital signal in digital domain. The **digital to analog converter** (DAC) and analog to digital converter (ADC) are two type of converter. These two type of converter use in day to day life to convert the signal into each other. A **digital to analog converter** converts a digital input to analog output. Digital signal is a combination of group of binary bits 0 and 1. In this tutorial we are going to discuss the digital to analog converter.

1. WHAT IS DIGITAL TO ANALOG CONVERTER (DAC)?

The digital to analog converter is an electronics device that convert digital input signal to analog output signal such as voltage or current. The digital signal is the combinations of the binary bits 0‘s and 1’s (or High & low voltage levels). These binary bit converts into analog signal such as voltage or current.



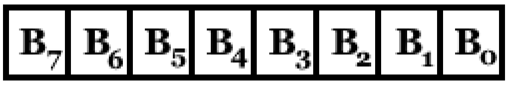


2. NEED OF DIGITAL TO ANALOG CONVERTER (DAC)

In our real world all information exists in the analog form. So, why we convert them into digital form in the first place if we want to convert them back? Because the processing speed of digital signal is high and digital computer process a data in few second with accuracy. It save time and solve any complex data. But in real word we cannot understand the digital data. In order to understand the digital data we need a digital to analog converter.

WORKING OF DIGITAL TO ANALOG CONVERTER (DAC)

The digital signal is a group of the **binary** bits 0’s and 1’s. Each bit has its own weight corresponding to its position. The position weight is 2^n where the n is the position of the bit & it start from 0, 1, 2…..



8-bit Binary Number

For example:

Convert **binary** number 10011 in to analog form;

$(10011)_2 = (1 \times 2^4) + (0 \times 2^3) + (0 \times 2^2) + (1 \times 2^1) + (1 \times 2^0)$

$(10011)_2 = 16 + 0 + 0 + 2 + 1$

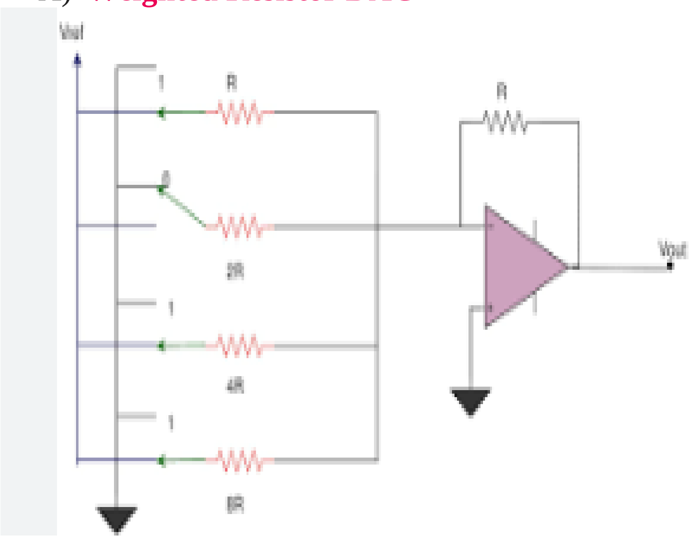
$(10011)_2 = 19$

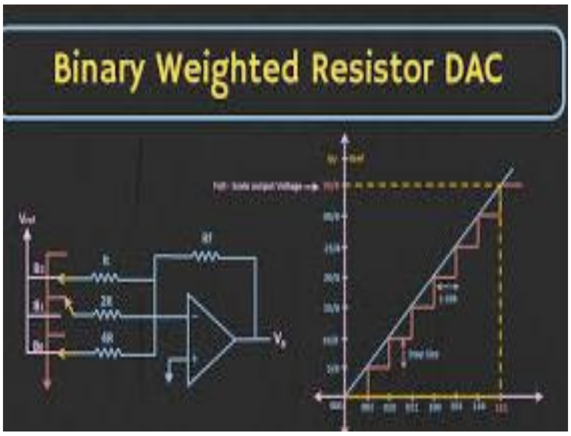
This shows how the **binary** digits convert in to analog form.

3. TYPES OF DIGITAL TO ANALOG CONVERTER (DAC)

There are **two types** of DAC

A) **Weighted Resistor DAC**

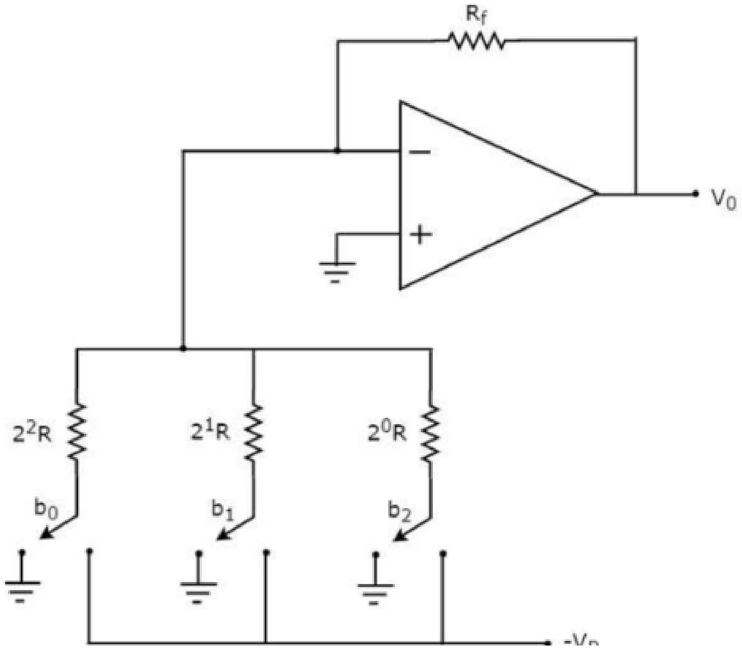




WEIGHTED RESISTOR DAC

A weighted resistor DAC produces an analog output from the digital input. The analog signal is almost equal to digital signal, a binary weighted resistor DAC is also known as weighted resistor DAC. Below the figure shows the circuit diagram of a 3-bit **binary** weighted resistor DAC.

BINARY WEIGHTED RESISTOR D/A CONVERTER CIRCUIT



Let the **3-bit binary input bit** is b_2 b_1 b_0. Here b_2 and b_0 are denotes the **Most Significant Bit (MSB) and Least Significant Bit (LSB)** respectively. The digital switches above the figure shows connection of b_2 b_1 b_0 to ground when ground input is equal to zero. Similarly, the digital switches are connected to –V_R when the corresponding binary input bits are '1'. The non-inverting terminal of the op-amp is connected to the ground terminal and the inverting terminal of the op-amp is connected to the digital switches. According to the virtual short concept the voltage of inverting input terminal is same to the non-inverting input terminal. So, the voltage of inverting terminal of Op-amp will be zero volts.

The **equation** of inverting input terminal is given below:

$$\frac{0+V_Rb_2}{2^0R}+\frac{0+V_Rb_1}{2^1R}+\frac{0+V_Rb_0}{2^2R}+\frac{0-V_0}{R_f}=0$$

$$=> \frac{V_0}{R_f}=\frac{V_Rb_2}{2^0R}+\frac{V_Rb_1}{2^1R}+\frac{V_Rb_0}{2^2R}$$

$$=> V_0=\frac{V_RR_f}{R}\left\{\frac{b_2}{2^0}+\frac{b_1}{2^1}+\frac{b_0}{2^2}\right\}$$

Substituting, $R=2R_f$ f in above equation.

$$=> V_0=\frac{V_RR_f}{2R_f}\left\{\frac{b_2}{2^0}+\frac{b_1}{2^1}+\frac{b_0}{2^2}\right\}$$

$$=> V_0=\frac{V_R}{2}\left\{\frac{b_2}{2^0}+\frac{b_1}{2^1}+\frac{b_0}{2^2}\right\}$$

The above equation shows the **output voltage equation** of a 3-bit binary weighted resistor DAC.

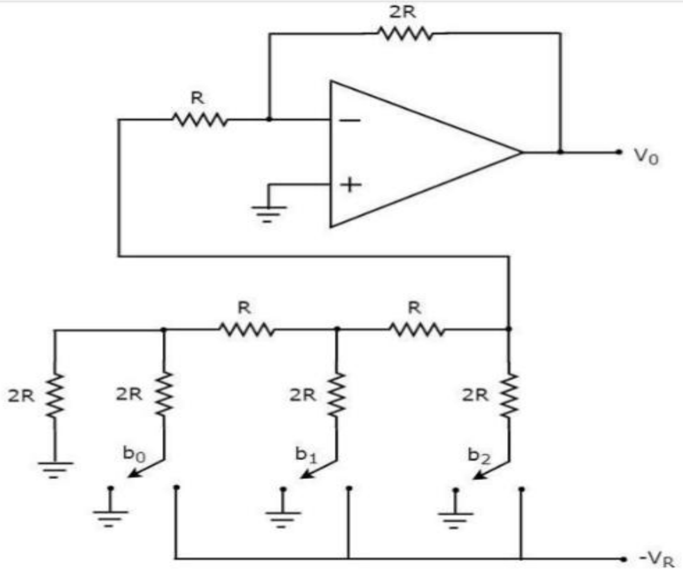
The **disadvantages** of a **binary** weighted resistor DAC are given below

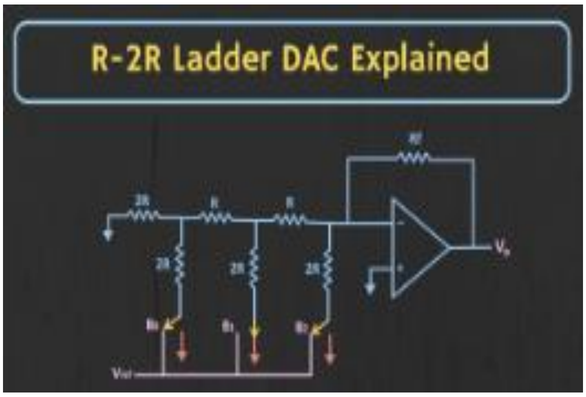
- Large resistance value required when increase inputs line.
- The value of large resistance is not accurate.
- It is difficult to design.

R-2R LADDER DAC

The R-2R Ladder DAC resolves the disadvantage of weighted resistance DAC. It is another type of digital to analog converter. When we giver digital input and obtained analog output. The circuit diagram of R-2R Ladder DAC is shown below.

B) LADDER D/A CONVERTER CIRCUIT





$$V_{out} = -V_{ref}\{B_0(1/2^N) + B_1(1/2^{N-1}) + B_2(1/2^{N-2}) + \ldots + B_{N-2}(1/2^2) + B_{N-1}(1/2^1)\}$$

Example:

Convert a binary number of 10110 into an analog output where the v_{ref} = 12v

The number of bit N = 5

$$V_{out} = -V_{ref}\{B_0(1/2^N) + B_1(1/2^{N-1}) + B_2(1/2^{N-2}) + \ldots + B_{N-2}(1/2^2) + B_{N-1}(1/2^1)\}$$

$$V_{out} = -V_{ref}\{B_0(1/2^5) + B_1(1/2^4) + B_2(1/2^3) + B_3(1/2^2) + B_4(1/2^1)\}$$

$$V_{out} = -(12)\{(0)(1/2^5) + (1)(1/2^4) + (1)(1/2^3) + (0)(1/2^2) + (1)(1/2^1)\}$$

$$V_{out} = -(12)\{(1/2^4) + (1/2^3) + (1/2^1)\}$$

$$V_{out} = -(12)\{(1/16) + (1/8) + (1/2)\}$$

$$V_{out} = -8.25\text{ v}$$

This type of conversion is more precise, easy to design and accurate. This circuit use combination R & 2R resistor in cascaded form which is shown in above figure. In this circuit we use only two type of resistor R & 2R. When we need zero to connected to GND switch, for 1's the switch shifted to V_{ref} . These switches are shifted by according to binary inputs.

ADVANTAGES OF R-2R LADDER DAC;

- It uses only two types of resistors R & 2R.
- Easily scalable to any number of bits
- Output impedance is always R

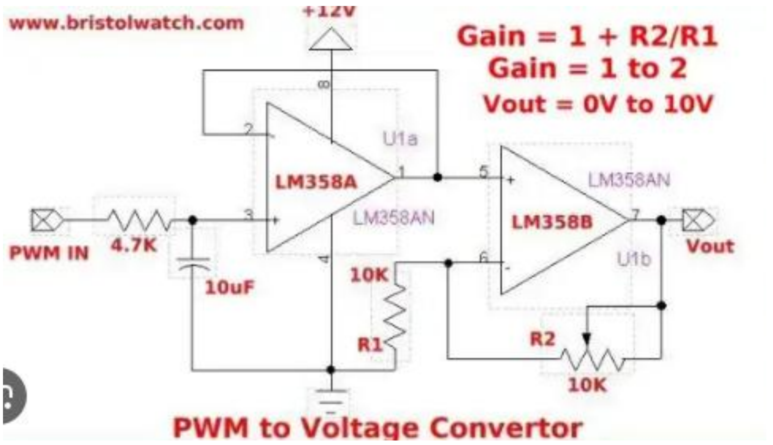
c) PWM Based Conversion

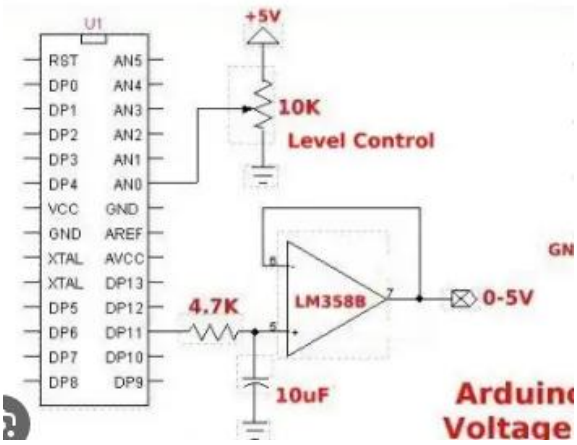
It is another method used in digital to analog converter & microcontrollers such as Arduino can be easily programed to utilize its PWM function to generate an analog output.

Pulse Width Modulation or PWM is a method of varying the average power of a signal by varying its duty cycle. He duty is the % turn on time of the signal, the % amount of time for which the signal remains high. Like 40% duty cycle signal means it stays high for 40% of time & stays low for 60%.

We can use a binary number to generate such type signal whose duty cycle depends on the binary digit. The PWM wave is the filtered using a low pass filter to remove the fluctuations & provide a smooth analog voltage.

The low pass filter used can be a first order. 2nd order low pass filter would be a great choice for a PWM base digital to analog converter.





4. Characteristics

Resolution of DAC

Resolution is the number of possible output levels a DAC can produce. It depends on the number of input bits.

$$\text{Resolution} = 2^n$$

The resolution of an n-bit DAC is 2^n. For example, a 4-bit DAC has resolution of 2^4 or 16 output levels.

Step Size of a DAC

The step size of a DAC is the smallest change in the analog output & it is the difference between two consecutive output voltage levels.

The step size can be calculated by dividing the range (maximum output voltage) or V_{ref} by 2^n where n is the number of bits.

$$\text{Step size} = \text{Range} / 2^n$$

For example, the step size of a 4 bit DAC with range of 5v is;

$$\text{Step size} = 5/2^4 = 5/16 = 0.3125\text{v}$$

The step size of this DAC is 0.3125. So for a single bit increment, its analog output will increase by 0.3125 v.

Increasing the resolution of a DAC decreases the step size & generates a smooth analog wave with much more accuracy.

5. Applications of DAC

Digital to analog converters are used in various applications to convert a digitally processed signal into an analog signal. Some of the various applications of a DAC are given below;

Audio:

The audio signal is analog in nature but it is converted using ADC (analog to digital converter) into digital format to edit & store in storage devices in various digital formats such as mp3, wav etc. The audio amplifier or the sound card in a system contains DAC that converts the audio signal stored in digital device into an analog signal. The signal can be modified by the amplifier by varying its gain (volume), bass, treble etc. & then converted into analog signal because the speaker cannot support a digital signal.

Video:

Digital video players utilize DAC to play any digital video using an analog monitor. These video players convert the digital signal from the digital source file into an analog signal.

A digital video player has digital video ports such as DVI or HDMI. But if it has any analog output ports (composite port of yellow color), it contains a DAC whose job is to convert the video file into analog signal.

Motor Control

One of the most important components in controlling a motor using a digital device such as a microcontroller is a DAC.

In various electronics projects, motor is embedded with a microcontroller. The microcontroller generates a digital signal to vary the speed of the motor which is converted into an analog signal using a **DAC (Digital to Analog Converter)**.

DISPLAY ELECTRONICS

It is use in graphic controller to generate analog output such as Red, Green, Blue (RGB) signals to drive a display.

Examples

Arduino Pulse-Width Modulation Digital to Analog Conversion

Here we will discuss the operation of pulse-width-modulation to DC conversion and use the idea to construct a variable Arduino based DC power supply.

Fig. 1 illustrates using a LM358 in conjunction with a low-pass filter (10uF cap, 4.7K resistor) to produce a 0-5V output proportional to the duty cycle from DP11. The 10K potentiometer connected analog pin 0 is read, divided by 4, then written with analogWrite() to digital pin 11. The reason we divided the ADC value by 4 is because the PWM as used with Arduino is 8-bit and not 10-bit. This same circuit works with a Microchip PIC as 10-bit with better resolution. The resolution is 5V / 255 = 19.61mV per step.

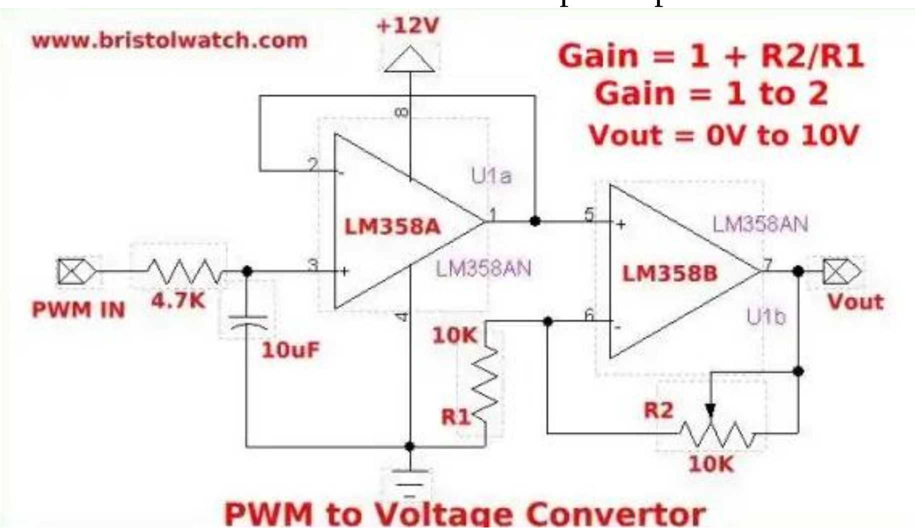


Fig. 2

Fig. 2 show using the other half of the LM358 as a voltage amplifier whose gain is based in 1 + R2/R1. With the 10K potentiometer connected between output pin 7 and fed back to the inverted input we can adjust for a gain of 1 to 2. The output with a 12-volt supply is 0-10V or 2-volts below Vcc.

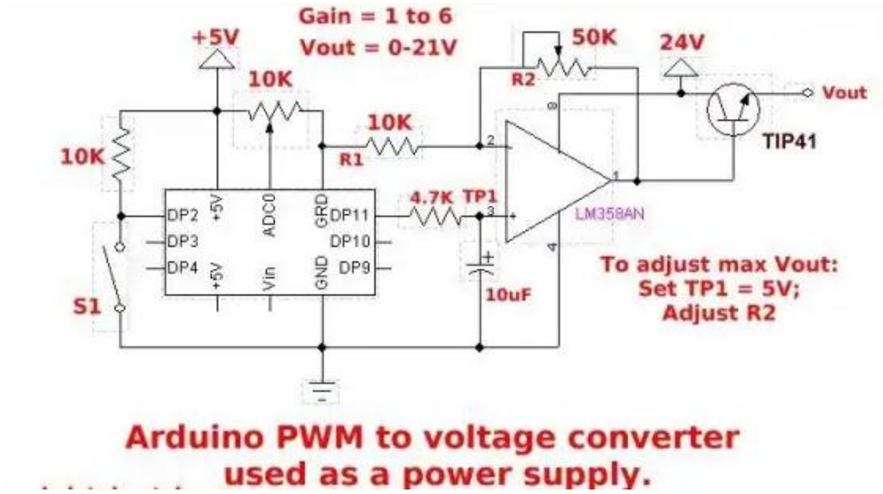


Fig. 3

In Fig. 3 we take the same circuit in Fig 2 but use a single LM358 as a voltage amplifier, boost Vcc to 24-volts, and change the 10K to 50K giving a gain of 1 to 6. We have also added a TIP41 NPN power transistor to boost output current.

First adjust the 10K pot on ADC0 for 5-volts at TP1, then adjust R2 for a maximum voltage out between 5 and 20-volts. While this is showing an Arduino NANO it will work with any Arduino.

Below is a sample program and if one wants to use an I2C LCD display that connection is illustrated below.

Out next project is to use the above in conjunction with a LM311 comparator to measure voltages up to 20-volts.

See Arduino Analog to Digital Conversion Voltmeter.

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
// set the LCD address to 0x27
// 2-lines 16-char numbered 0-15
LiquidCrystal_I2C lcd(0x27,16,2);

int potValue;

void setup(void) {
  lcd.init(); // initialize the lcd
  lcd.backlight();
}

void loop(void) {

  potValue = analogRead(0) / 4 ;
  analogWrite(11, potValue);
  lcd.print("potValue =       ");
  lcd.setCursor(11,0);

  lcd.print(potValue);
```

```
  lcd.home();
  delay(200);
}
```

Reference

[1] https://www.knowelectronic.com/digital-to-analog-converter/

[2] https://www.electricaltechnology.org/2020/04/digital-to-analog-converter-dac.html

[3] https://www.bristolwatch.com/ele2/dac.htm