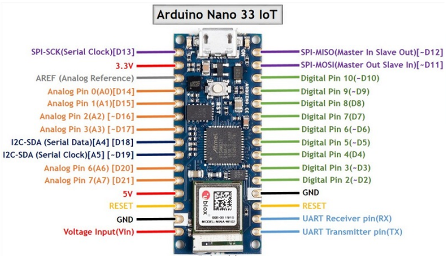
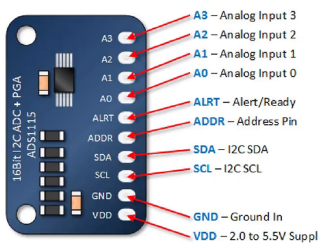
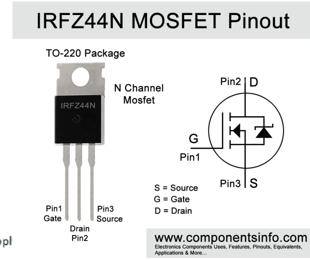
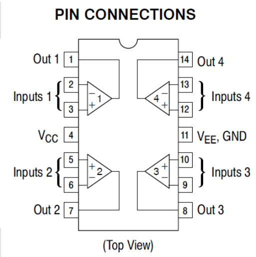








Basic Electronic Load Circuit

Main Elements:

1, Arduino Nano IoT - power supply + serial communication with ADC and LCD

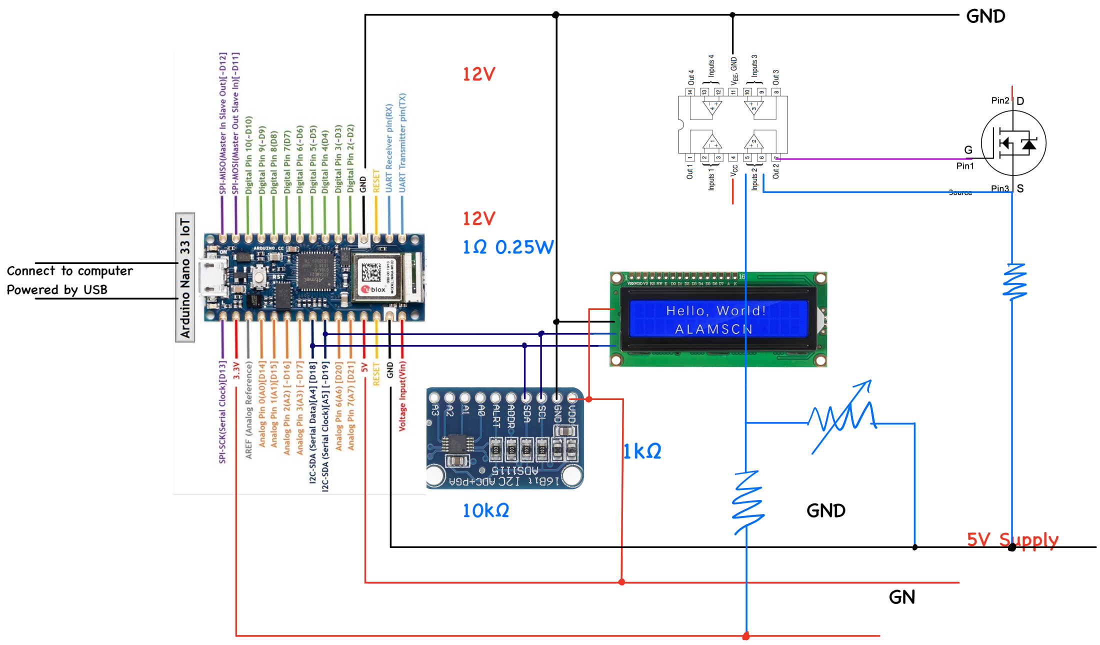
2, ADS1115 - analog to digital converter - be able to measure 4 points

3, LCD Display - show important results simultaneously

4, LM324N - single supply amplifier - comparator

5, IRFZ44N MOSFET - power MOSFET - act as an resistive element under control

Circuit Representation



This circuit can use 1KΩ rotary potentiometer to adjust the set reference voltage from 0V to 0.3V, and the current through Rsense can be controlled from 0A to 0.3A. Notice: 1Ω 0.25W resistor here - 0.3A*0.3A*1Ω = 0.09W sufficient.

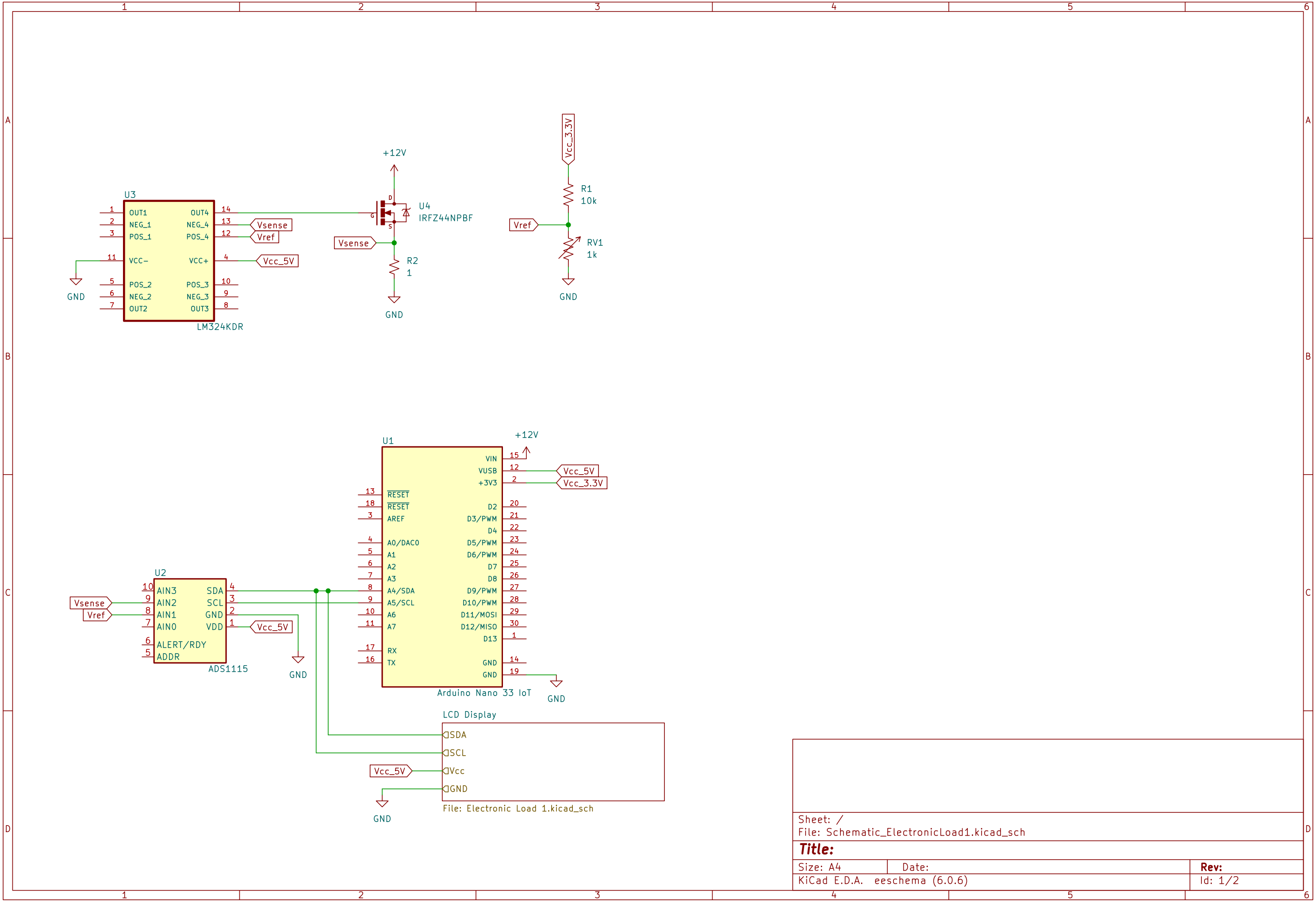
Now this circuit can be used as larger than 33Ω load design

Results from ADC measurement:

16:27:31.550 -> AIN0: 0.34
16:27:31.550 -> Vref: 107.34mV
16:27:31.550 -> Isen: 107.03mA
16:27:31.550 -> AIN3: 0.33
16:27:31.550 ->
16:27:32.573 -> AIN0: 0.34
16:27:32.573 -> Vref: 106.87mV
16:27:32.573 -> Isen: 106.25mA
16:27:32.573 -> AIN3: 0.34
16:27:32.573 ->
16:27:33.645 -> AIN0: 0.33

```
16:27:33.645 -> Vref: 109.06mV
16:27:33.645 -> Isen: 108.59mA
16:27:33.645 -> AIN3: 0.34
16:27:33.645 ->
16:27:34.674 -> AIN0: 0.34
16:27:34.674 -> Vref: 103.28mV
16:27:34.674 -> Isen: 102.81mA
16:27:34.674 -> AIN3: 0.34
16:27:34.674 ->
16:27:35.704 -> AIN0: 0.33
16:27:35.704 -> Vref: 106.87mV
16:27:35.704 -> Isen: 104.84mA
16:27:35.704 -> AIN3: 0.33
16:27:35.704 ->
16:27:36.733 -> AIN0: 0.33
16:27:36.733 -> Vref: 102.66mV
16:27:36.733 -> Isen: 102.19mA
16:27:36.733 -> AIN3: 0.33
16:27:36.733 ->
16:27:37.762 -> AIN0: 0.33
16:27:37.762 -> Vref: 100.78mV
16:27:37.762 -> Isen: 100.78mA
16:27:37.809 -> AIN3: 0.33
16:27:37.809 ->
16:27:38.835 -> AIN0: 0.33
16:27:38.835 -> Vref: 106.72mV
16:27:38.835 -> Isen: 106.25mA
16:27:38.835 -> AIN3: 0.33
16:27:38.835 ->
16:27:39.863 -> AIN0: 0.33
16:27:39.863 -> Vref: 106.41mV
16:27:39.863 -> Isen: 105.00mA
16:27:39.863 -> AIN3: 0.33
16:27:39.863 ->
16:27:40.890 -> AIN0: 0.33
16:27:40.890 -> Vref: 96.72mV
16:27:40.890 -> Isen: 95.78mA
16:27:40.890 -> AIN3: 0.36
16:27:40.890 ->
16:27:41.918 -> AIN0: 0.33
16:27:41.918 -> Vref: 97.50mV
16:27:41.918 -> Isen: 98.12mA
16:27:41.918 -> AIN3: 0.34
16:27:41.918 ->
16:27:42.994 -> AIN0: 0.33
16:27:42.994 -> Vref: 95.31mV
16:27:42.994 -> Isen: 95.00mA
16:27:42.994 -> AIN3: 0.33
16:27:42.994 ->
16:27:47.106 -> AIN0: 0.34
16:27:47.153 -> Vref: 284.22mV
16:27:47.153 -> Isen: 278.75mA
16:27:47.153 -> AIN3: 0.34
16:27:47.153 ->
16:27:48.180 -> AIN0: 0.33
16:27:48.180 -> Vref: 273.75mV
16:27:48.180 -> Isen: 273.44mA
16:27:48.180 -> AIN3: 0.34
16:27:48.180 ->
16:27:49.212 -> AIN0: 0.34
16:27:49.212 -> Vref: 274.22mV
16:27:49.212 -> Isen: 268.44mA
16:27:49.212 -> AIN3: 0.34
16:27:49.212 ->
16:27:50.238 -> AIN0: 0.33
```

```
16:27:50.238 -> Vref: 220.16mV
16:27:50.238 -> Isen: 200.31mA
16:27:50.238 -> AIN3: 0.34
16:27:50.238 ->
16:27:51.268 -> AIN0: 0.34
16:27:51.268 -> Vref: 74.53mV
16:27:51.268 -> Isen: 74.84mA
16:27:51.268 -> AIN3: 0.33
16:27:51.268 ->
16:27:52.344 -> AIN0: 0.34
16:27:52.344 -> Vref: 68.59mV
16:27:52.344 -> Isen: 67.97mA
16:27:52.344 -> AIN3: 0.33
16:27:52.344 ->
16:27:53.374 -> AIN0: 0.34
16:27:53.374 -> Vref: 68.91mV
16:27:53.374 -> Isen: 68.12mA
16:27:53.374 -> AIN3: 0.34
16:27:53.374 ->
```



U3
OUT1
NEG_1
POS_1
VCC-
POS_2
NEG_2
OUT2
OUT4
NEG_4
POS_4
VCC+
POS_3
NEG_3
OUT3
LM324KDR
Vsense
Vref
Vcc_5V
GND
+12V
U4
IRFZ44NPBF
R2
1
Vcc_3.3V
R1
10k
RV1
1k
U1
VIN
VUSB
+3V3
RESET
AREF
A0/DAC0
A1
A2
A3
A4/SDA
A5/SCL
A6
A7
RX
TX
D2
D3/PWM
D4
D5/PWM
D6/PWM
D7
D8
D9/PWM
D10/PWM
D11/MOSI
D12/MISO
D13
Arduino Nano 33 IoT
U2
AIN3
AIN2
AIN1
AIN0
ALERT/RDY
ADDR
SDA
SCL
VDD
ADS1115
LCD Display
SDA
SCL
Vcc
GND
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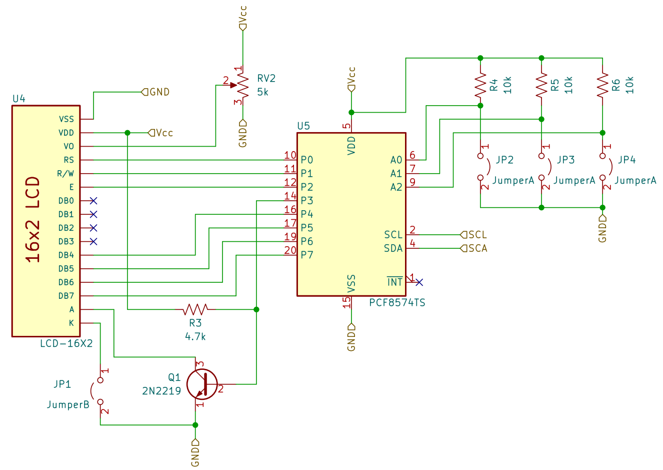

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Title:

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Plan for next step:

1, Arduino PWM output - convert it into analog voltage, which is used for Vref.

Just add stages of RC type low-pass filters (might need two stages) then add one non-inverting amplifier to balance the attenuation.

Duty cycle determines the voltage output.

PWM frequency determines the amount of attenuation the filter can produce. PWM frequency is set, according to the attenuation that provided from our best performance RC filter, the deign of our amplifier is therefore set.

=> Add non-inverting amplifier to compensate the attenuation cost in the front RC filter.

=> Vref range depends on sense resistor we use in the circuit, 4A max output for 0.5Ω power resistor, Vref = [0, 2]; Arduino PWM output 0 to 3.3V, 2/3.3 -> 60.6% duty cycle.

When the PWM frequency is close to the cut-off frequency, the filter response quickly, but produce a high amount of ripple in the output signal. In order to have as less ripple as possible in the output signal, which is used as reference voltage to control, we should scarify the response time, since it is unnecessary to have quick response when we try to change the reference voltage.

=> set cut-off frequency as low as possible - small capacitance and high resistance & more stages

- Fc=1/2*pi*RC - 10k & 10uF - 1.59Hz cut-off frequency.

→ 20mA ~ 1A

- Attenuation plot, it depends on PWM signal Fourier Transform, amplitude of DC signal will be the final result. - check by experiment

TimerOne → 250Hz → Vref 10mV ~ 500mV (Rs=0.5Ω)

- Circuit linearity and output resolution - add voltage follower to improve linearity. Because it can isolate front and after circuit (zero input current, avoid loading effects), less Rout and high Rin, high frequency noise can be filter out, unity gain for voltage & high current gain. <Active filter>

(Allow high impedance source and low impedance load, avoid voltage reduction when the load has low impedance while the input impedance is high).

Voltage Follower Stability: To avoid self excitation due to harmonic component with phase shift.

two stages of RC filters + voltage follower.

https://blog.actorsfit.com/a?ID=00600-64b3e80e-e00c-42cb-9f8b-2ff9299333bc

2, Convert this circuit into constant resistance

Approach 1: Voltage divider - need to adjust the resistor in the divider to control the set load overall resistance (digital potentiometer is still on the way, can use rotary potentiometer to verify). This approach is not good since Arduino control Vref for two operation mode will be consistent and easy to approach just by setting the right code.

Approach 2: Detect the source voltage by ADC module, and Arduino control the reference voltage based on the source voltage

This may have longer response time - can be acceptable due to the education purpose, do not need transient response when change the load resistance.

3, Relay - short circuit for the buck converter

Use Arduino to control the relay and check it can survive under 0.5V and 5A.

4, LCD display - try code to display on LCD

Display reference voltage & sense resistor current (this need to be differential since the Vout- from the converter is not equal to the ground)

(Problem Solved)

5, Temp monitor + Fan control:

Temp monitor: RTD temp sensor:

```
int ThermistorPin = 0;
int Vo;
float R1 = 10000;
float logR2, R2, T;
float c1 = 1.009249522e-03, c2 = 2.378405444e-04, c3 = 2.019202697e-07;

void setup() {
Serial.begin(9600);
}

void loop() {

  Vo = analogRead(ThermistorPin);
  R2 = R1 * (1023.0 / (float)Vo - 1.0);
  logR2 = log(R2);
  T = (1.0 / (c1 + c2*logR2 + c3*logR2*logR2*logR2));
  T = T - 273.15;
  T = (T * 9.0)/ 5.0 + 32.0;

  Serial.print("Temperature: ");
  Serial.print(T);
  Serial.println(" F");

  delay(500);
}
```

Fan Control: Logic level translation + MOSFET switch on (since the fan working voltage is 12V)

```
Vvoid fanOn(){
  digitalWrite(fan, HIGH);
}
void fanOff(){
  digitalWrite(fan, LOW);

}
```

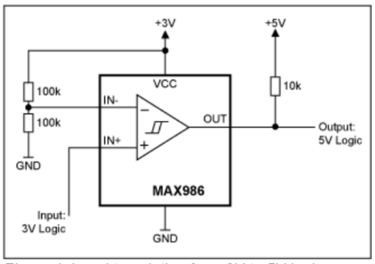

Figure 4. Level translation from 3V to 5V logic.

Since we use LM324 as our single supply amplifier - no need to add pull up resistor in the end.
The minimum power supply for LM324 is 3V, we give it 5V to build a simple comparator.
3.3V logic level - V+ compare it with 1.5V reference voltage.
If the logic level is low - 0.8V then output 0 V, which shut down the MOSFET and turn off the fan.
If the logic level is high - 3.3V then output 5V, which turn on the MOSFET and the fan.
(For irfb7545 MOSFET, 5V is sufficient to turn on, gate threshold voltage max is 3.7V)

6, Finish Dissertation Chapter 1 Introduction