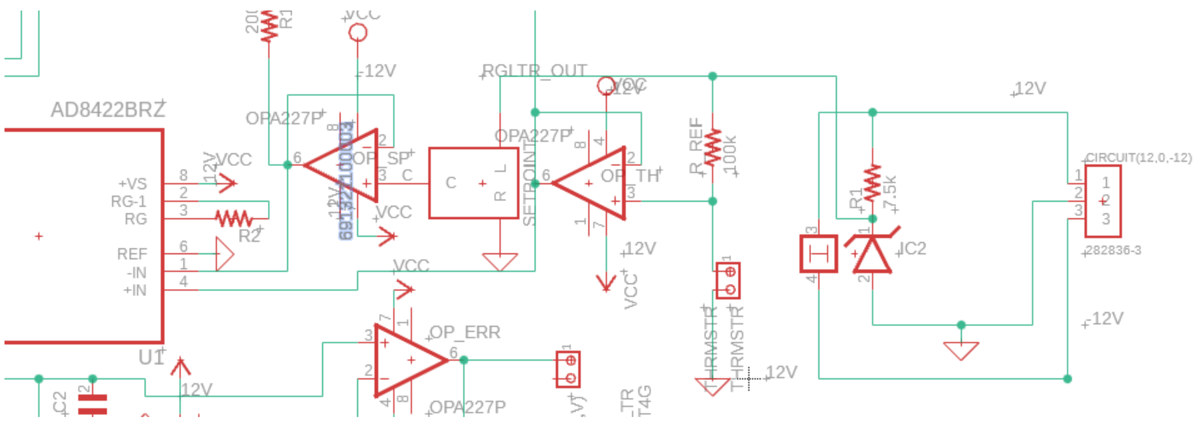
Temperature controller circuit

Authored by- Shobhit Saheb Dey
Supervision- Abhishek Menon and Prof. Guido Pagano

Sensor circuit

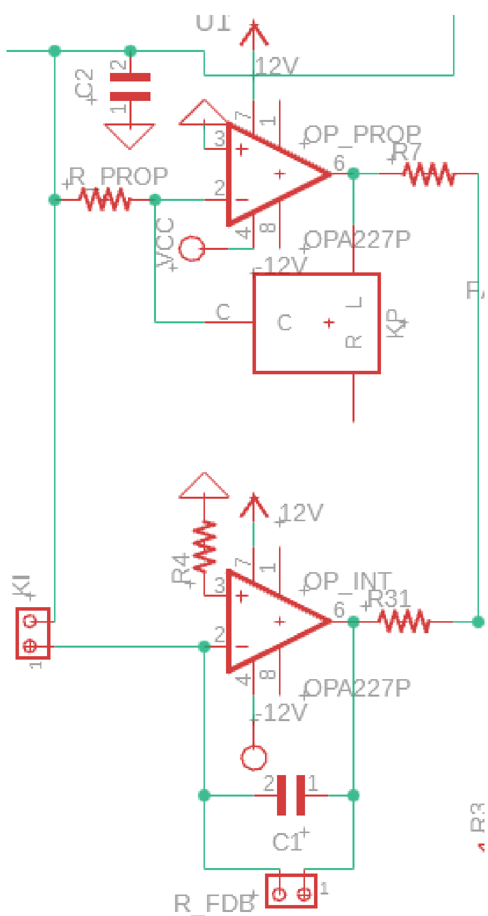


In order to provide negative feedback to the PID circuit, we need to sense the temperature of the diode in real time. For that we use a thorlabs thermistor whose resistance increases with decreasing temperature. So a desired resistance of the thermistor would correspond to a desired temperature of the diode. In this circuit we use a wheatstone bridge to generate an error signal voltage generated due to deviation of this resistance value from the desired one.

On one branch of the bridge we have a reference resistor R_REF and the thermistor(THRMSTR). On the other branch we keep a rheostat that divides up into 2 resistors say r1 and r2. Now when the wheatstone bridge is balanced, i.e r1/r2 = R_REF/THRMSTR, the potential at the junctions of the bridge become same, otherwise they generate a positive or negative voltage across them depended on the real time resistance of THRMSTR. We need to pickup the potential from these 2 points *without drawing any current.* So we place voltage follower opamps OP_TH and OP_SP to pickup the voltage and send these to the instrumentation amplifier AD8422 that would amplify the difference between these two by about 200(controlled by the resistor R2 connected) and output the error signal finally for the PID's feedback.

Here, some nuances should be kept in mind. The voltage generated by the wheatstone bridge can be affected by 2 unwanted noise/drift sources. On end of the bridge is grounded(which we can assume to be fairly clean since we use acopian or some other power supply that provides ground. But the other end's voltage should be regulated, which is done here by LM399H. The 7.5kOhm resistor R1 seen in the circuit is to ensure the current passing through the zenner of the LM399H in the operating region for 7V output. If any other output is measured, you probably need to tune this resistor.

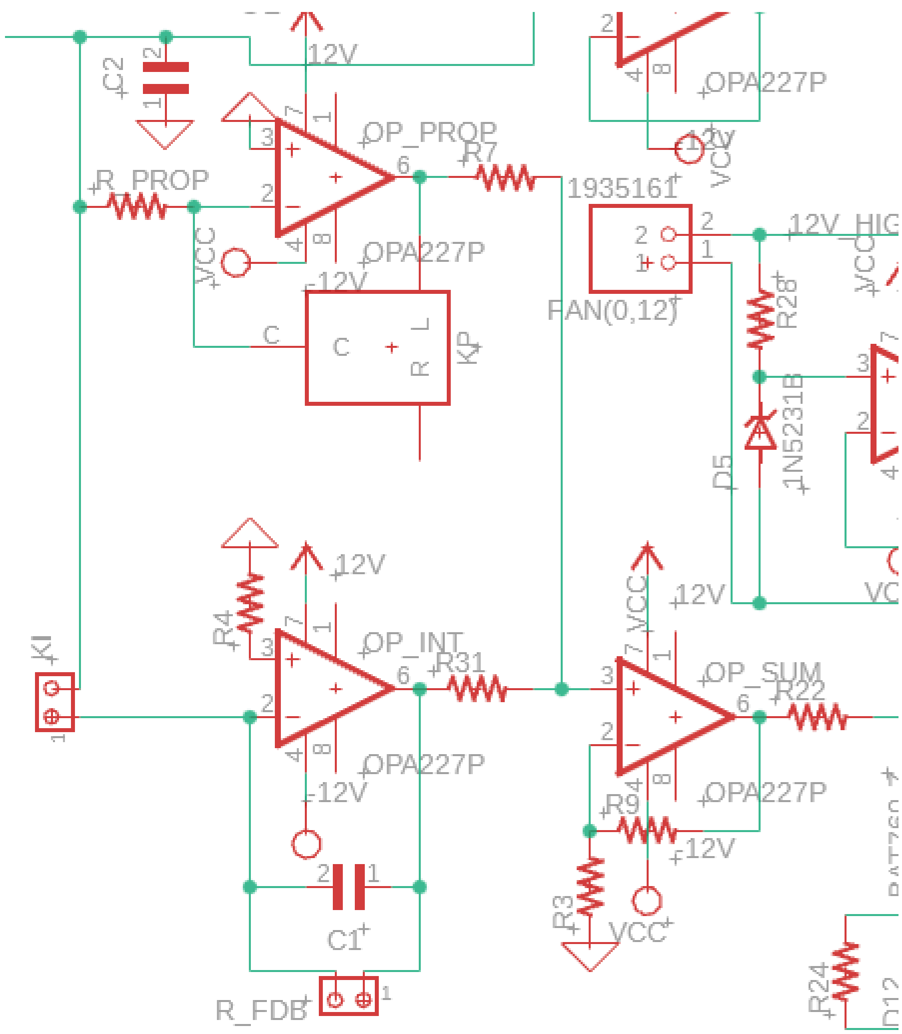
Proportional and Integral Circuit



We use opamps in inverting amplifier configuration to get proportional and integral of the error signal. The proportional part is pretty straightforward, we put a rheostate on the feedback resistor to tune the Kp value. The integral part is standard too, but we add the optional resistors R_FDB and R4. The feedback resistor is to handle the high frequency integration and R4 is to avoid any slow drifts in the ground.

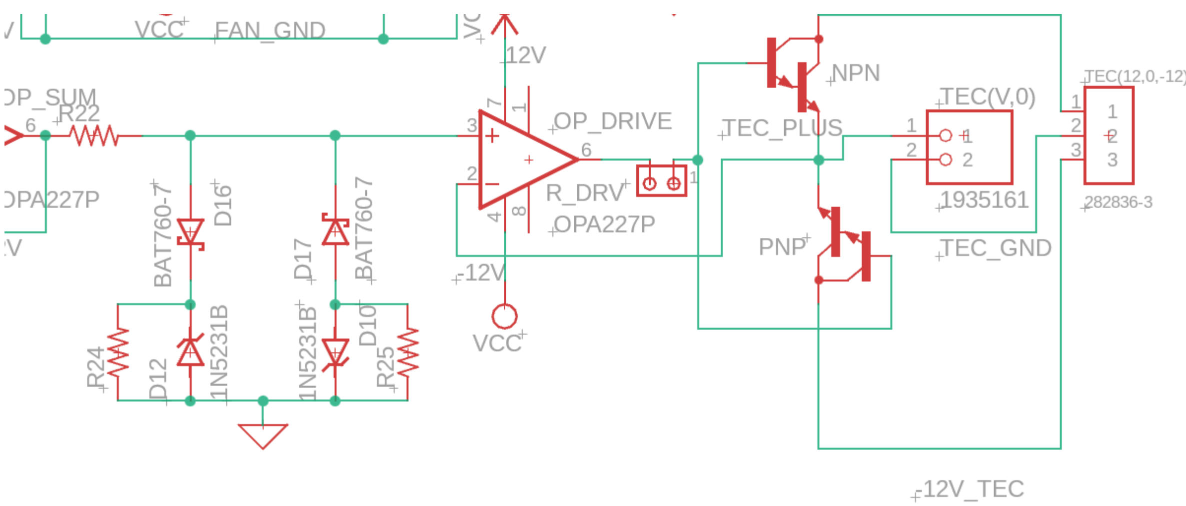
Here, if needed, KI can be kept for a fixed resistor of say 5MOhm or you can also use rheostat, but would not be very necessary.

Summing



Here we sum the proportional and the integral signals to finally generate the control signal. Let the corresponding outputs be V_prop and V_int. We keep R7 and R31 equal, say 100Ohm each, so we get (V_prop + V_int)/2 at the input of OP_SUM. Now is the output voltage of OP_SUM is V_sum, then for the positive input terminal, the voltage gets divided again into half as we keep R9 and R3 equal too. But here we need to keep both of them much higher than the output impedance of the opamp to avoid unwanted voltage drop towards ground, so lets keep them 1kOhm each. So the feedback loop would equate (V_prop + V_int)/2 with V_sum/2 hence giving the sum as output.

Driver Circuit



OP_Sum here can give any output ranging in (-12V,12V) and we need to apply this control signal to our thermoelectric cooler(TEC), which typically has about 3Ohm of resistance. Hence, we would have to supply several amperes of current through the TEC and consistently for weeks/months. It is never advisable to supply that kind of current from an opamp for long times. So we need to mirror the voltage in such a way that current passes through a high power transistor instead. This is exactly what the driver circuit would do.

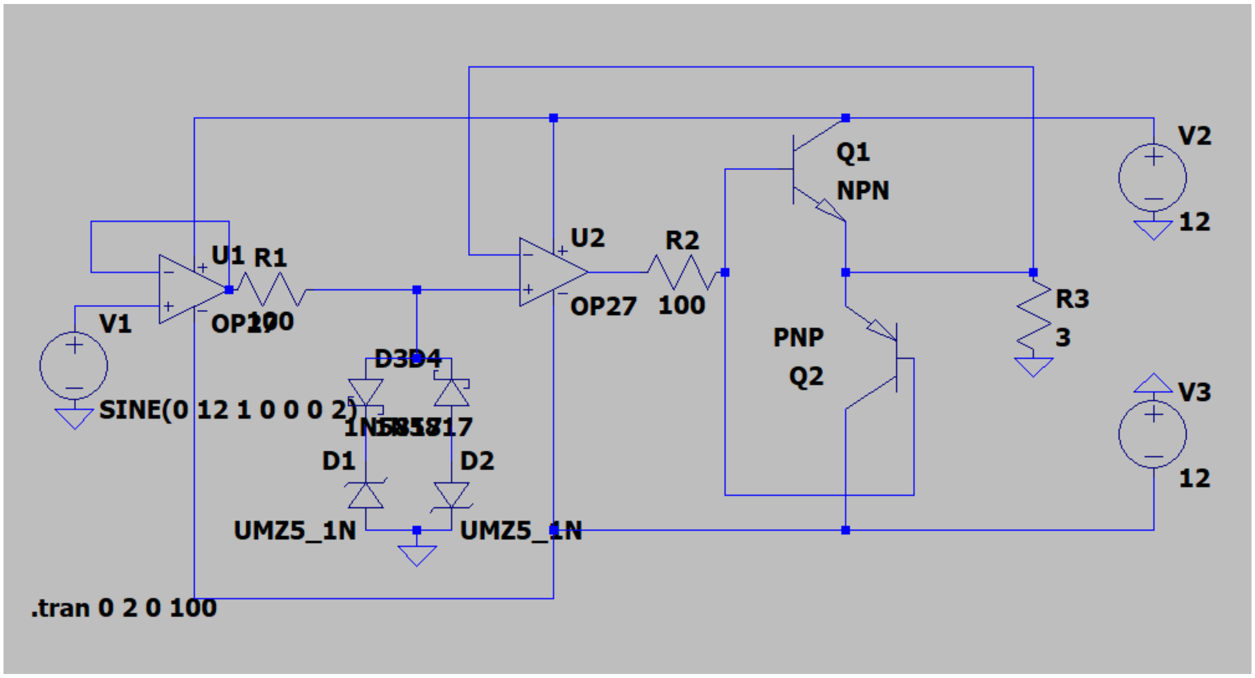
For now, ignore the pi-type config of 4 diodes before the OP_DRIVE, the function of that will be explained soon. So we have (-12V,12V) of voltage coming in the positive input of

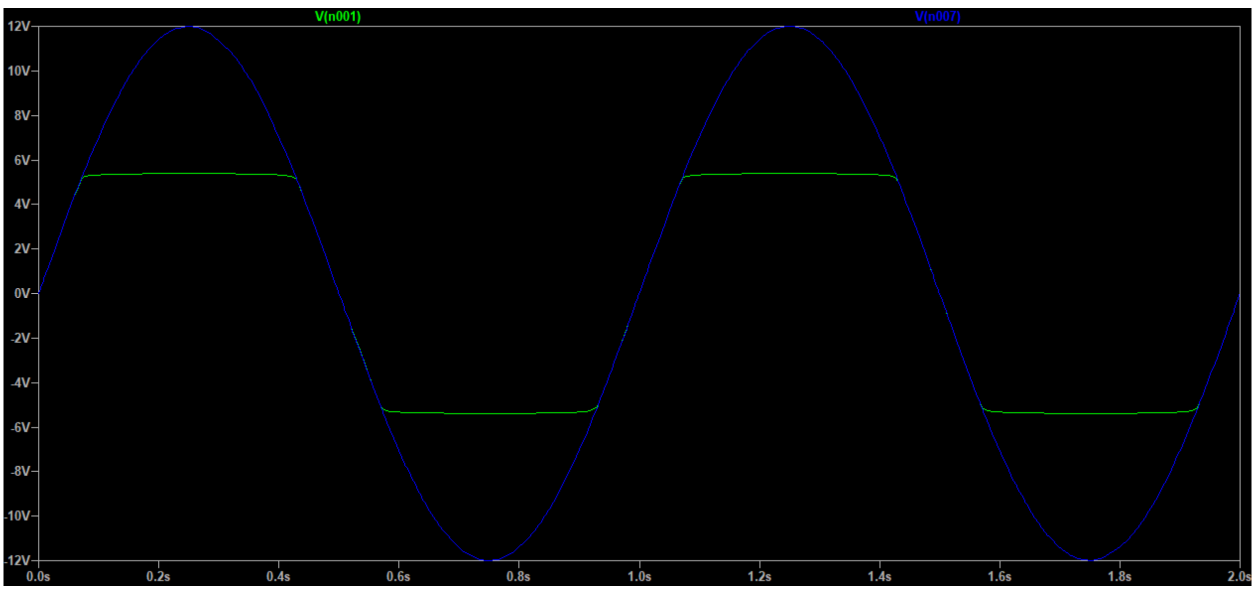
OP_DRIVE. Consider, a random voltage from the positive half of the range, say 3V. The output is connected to the base of the NPN transistor whose collector is supplied by 12V and the emitter is connected to TEC. The emitter voltage is also fed back to OP_DRIVE. So the OP_DRIVE would increase the output voltage until the emitter voltage equals. So 1A of current would flow through the TEC. Because the input impedance of the opamps are ~1MOhm, all of this current is supplied by the emitter. Now suppose we are using a standard darlington transistor, which has a DC-current amplification of about 2000, it means just a few mA of current flows from the output of the opamp into the base, and the rest is supplied from the collector terminal of the transistor. This is exactly what we wanted, the voltage gets mirrored but the current is not supplied by the opamp but by the transistor.

For the negative range of input voltages, the PNP-transistor would come into play while the NPN-transistor gets biased in switch-off mode, and the same process occurs.

Now coming to the diodes we places before the input terminal. Because we will be using 12V or 15V supplies(standard among acopians or other power supplies), it means at any point, the TEC can be supplied with 15V. But the standard TECs are rated for a maximum of 9V so it is advisable to keep it at around 4-5V for consistent usage. In the network of diodes, ignore the optional shunt resistors R24 and R25.

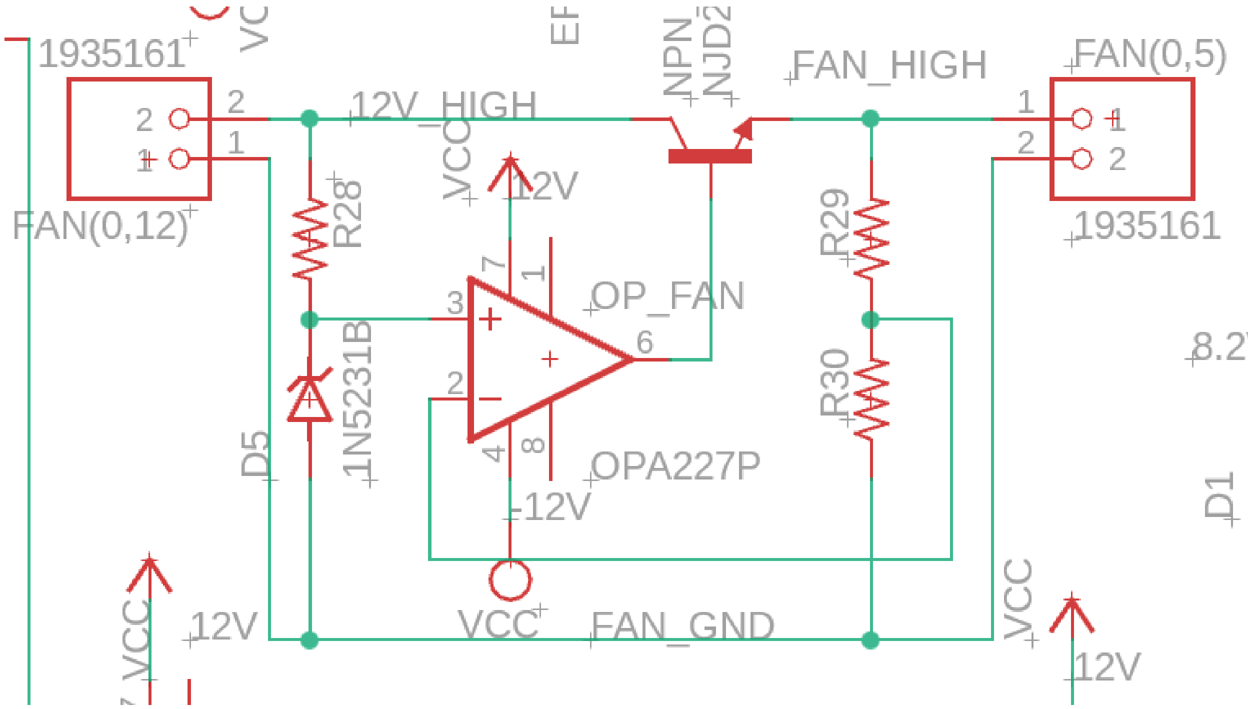
We have placed two lines of a schottky and a zenner diode. The zener diode has a breakdown voltage of 5V and schottky diode has a turn on voltage of ~300mV. When the output voltage of OP_SUM is more than 5V, one of zenners get saturated and avoids the voltage input to the OP_DRIVE to go beyond that. And when the OP_SUM gives less than -5V, the other zener gets saturated. This way we limit the voltage range of control signal to (-5V,5V). The resistor at the output of OP_SUM, R22 is kept to limit the current to the zenner according to its power rating. For example we have a 500mW zenner, then the maximum current it can take is 500mW/5V = 100mA. So the resistance should be such that the voltage drop between output of OP_SUM and zenner produces 100mA i.e (15V-5V)/100mA = 100Ohm. So we can keep 150-200Ohm for R22. Bellow is an LTSPICE simulation of a dummy circuit similar to this, where the control signal is a sinusoid and we show that the voltage at the TEC does get clipped.





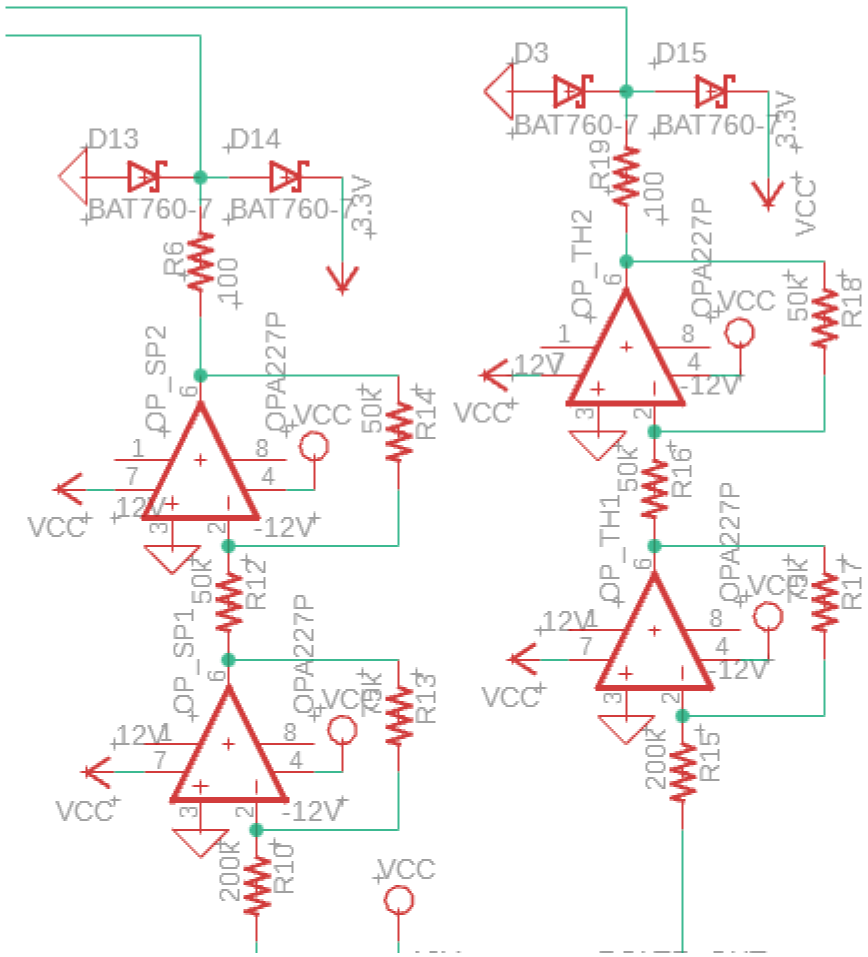
Fan power

The transistors used in the driver circuit get heated up pretty quickly and some active cooling is required for them, apart from just placing heat sinks on top of them. For this we use a normal CPU-fan that operates on 5V, 200mA. We would have to use a separate 5V supply other than the acopians but that would make the box messy. So eventhough it might be a overkill, might be helpful. So we need to downcovert 15V to 5V and yet supply good amount of current. Voltage dividers consume power and are load dependent while the zenners have a limit on how much of current they can provide. So just like in the driver circuit, we need to bypass the current through a transistor instead. Following is a circuit that can be in general used to make high-power voltage regulators:



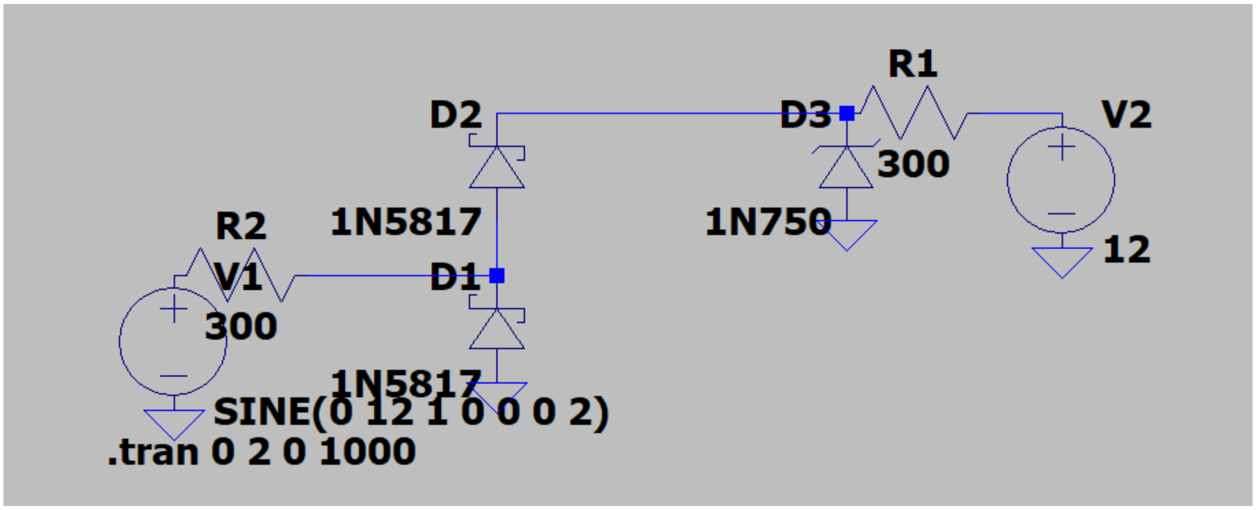
Here first the zenner is operated at the saturation voltage of 3.3V powered by a 12V or 15V supply and the resistance R28 is adjusted according to the power rating. This voltage is picked up and is matched with a resistive divider made of R29 and R30. So the emitter of the transistor will be at a potential such that the divided voltage equals 3.3V. And this emitter voltage is the regulated voltage we can use. We can change the ratio to tune the regulated voltage to anywhere but above 3.3V and all the load current is bypassed from the transistor and not from the zener or the opamp.

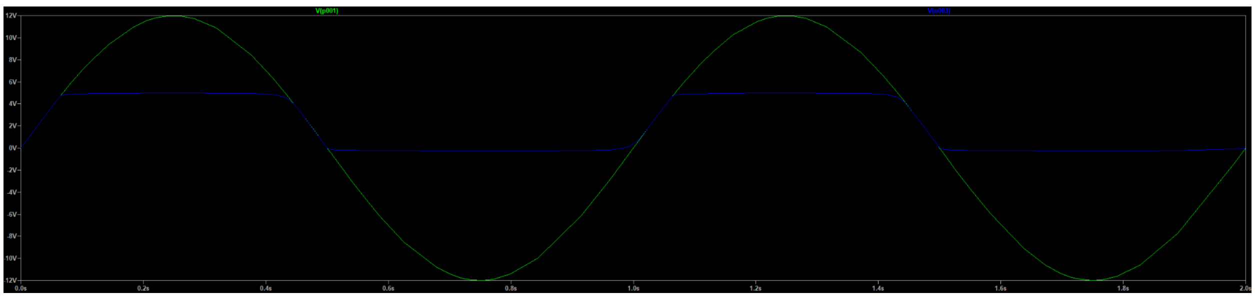
Voltage Protection



These two series of opamps in inverting amplifier config pick up voltage from thermistor and the setpoint rheostate and output 3/8th of them. Further the voltage is clamped between 0V and 3.3V for the protection of arduino's pins. The 3.3V source connected to the diode D14 and D15 is also produced by an onboard 12V to 3.3V convert using a zenner. Similarly 8.2V is created to power the arduino.

And LTSPICE simulation of the voltage clamping is below:

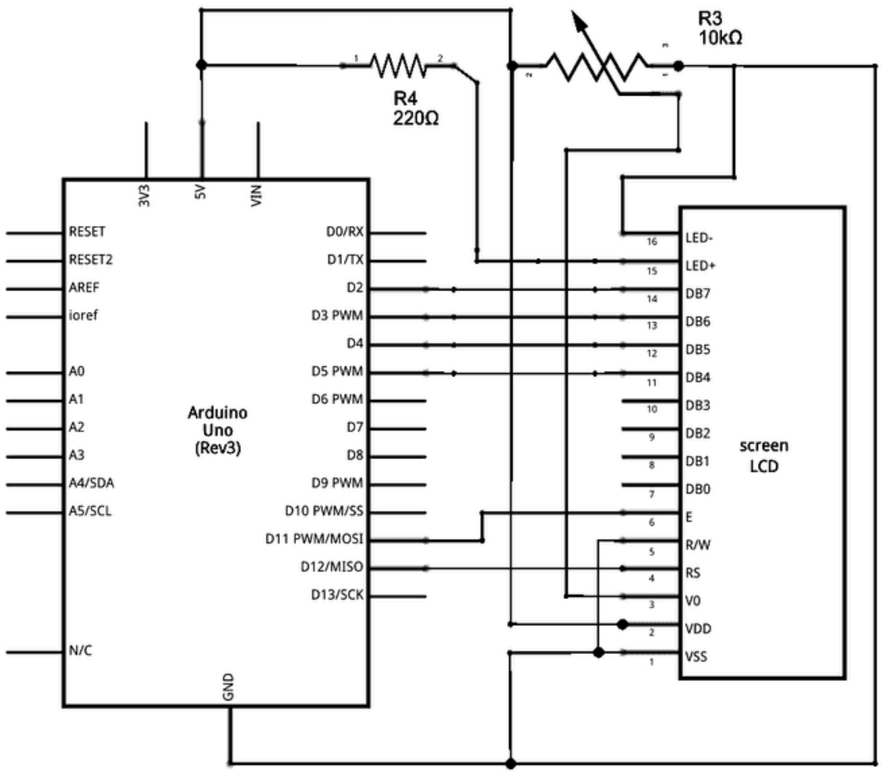


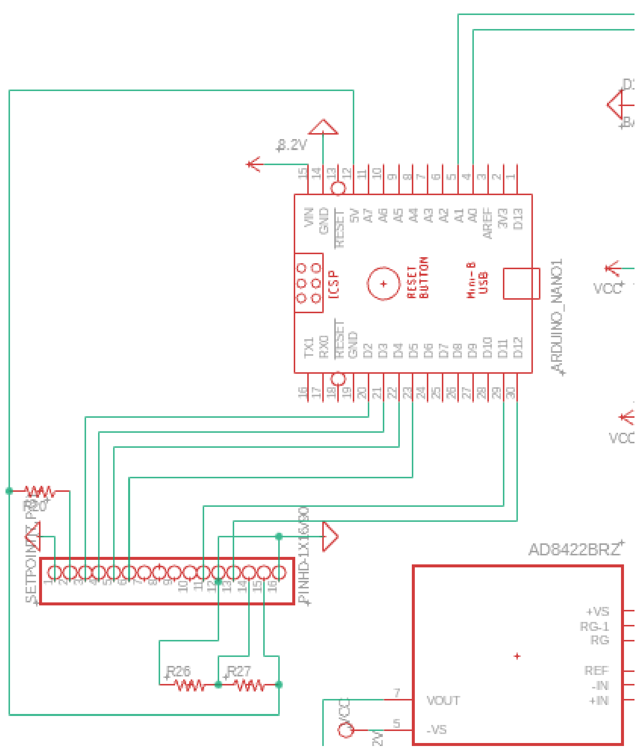


Here again all the resistances have to be chosen based on the rating of the zenners and schottky diodes used.

Arduino

We will be using an arduino to take analog input of voltages from setpoint rheostat and the thermistor and display digitally the current and setpoint temperature in an LCD. So the circuit for connecting the LCD to the onboard arduino need to be made. Please refer to [this tutorial] to understand the protocol of communication but the recommended circuit according to the tutorial is the following:


R3
10kΩ
R4
220Ω
3V3
5V
VIN
RESET
RESET2
AREF
ioref
A0
A1
A2
A3
A4/SDA
A5/SCL
N/C
Arduino
Uno
(Rev3)
D0/RX
D1/TX
D2
D3 PWM
D4
D5 PWM
D6 PWM
D7
D8
D9 PWM
D10 PWM/SS
D11 PWM/MOSI
D12/MISO
D13/SCK
GND
LED-
LED+
DB7
DB6
DB5
DB4
DB3
DB2
DB1
DB0
E
R/W
RS
V0
VDD
VSS
screen
LCD


8.2V
VIN
GND
RESET
5V
A7
A6
A5
A4
A3
A2
A1
A0
AREF
3V3
D13
ICSP
RESET BUTTON
Mini-B USB
TX1
RX0
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
ARDUINO_NANO1
VCC
R26
R27
PINHD-1X16/90
AD8422BRZ
+VS
RG-1
RG
REF
-IN
+IN
VOUT
-VS