Embedded System Design Course

Project: Design controller system for DC motor

Class: EE-E8-01 K63 Group: 14

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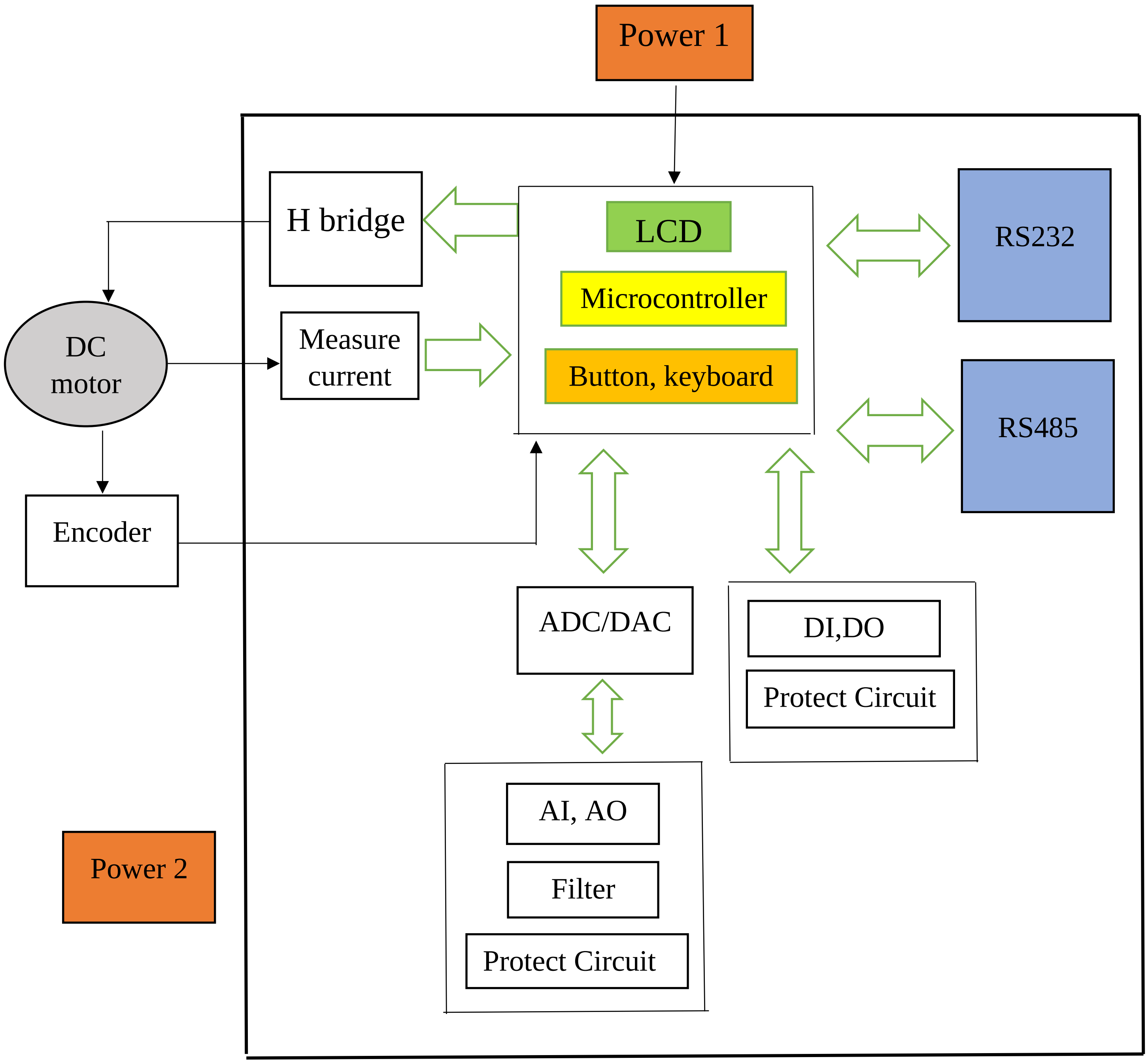
I. Overview

The content of this project is design an embebded controller for DC motor , device designed above for speed and direction control applications for motors in general, the motor of the conveyor...This device also supports serial data transmission of the motor via RS232 and RS485 protocol.

I. Specifications of project

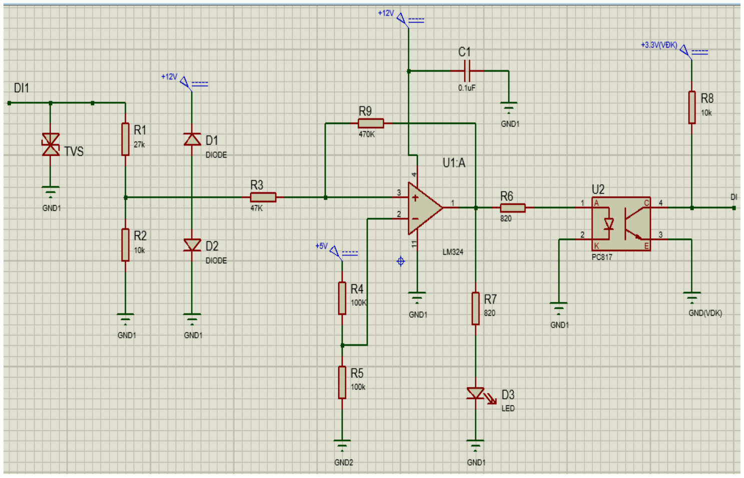
DC motor	24 V DC – 100 W
Supply voltage	24 V DC
Curent max	20A
Communicate	RS232 ,RS485
Input	4 Digital input (V=10-36V) 4 Analog input (V=0-10V;I=4-20mA)
Output	4 Digital output (V=24V) 4 Analog output (V= 0-10V ; I= 4-20mA)
Drive	H bridge
User interface	LCD 16x2 ,button, keyboard
Control mode	Speed, position, moment

II. Block diagram

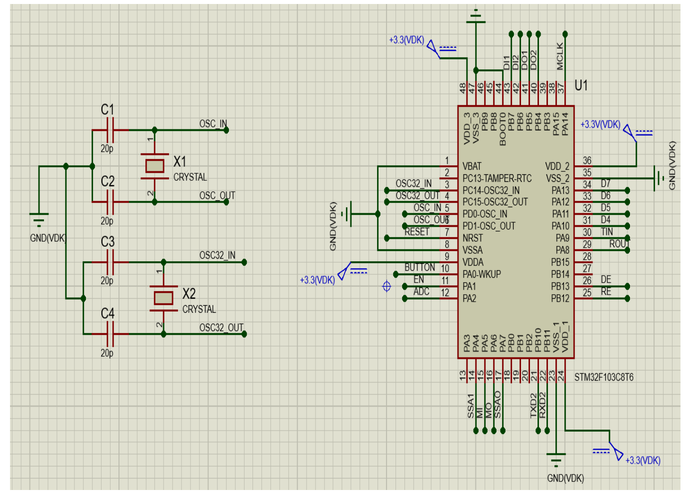


SCHEMATIC PROJECT

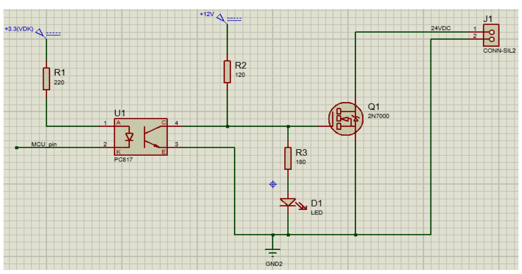
Digital Input

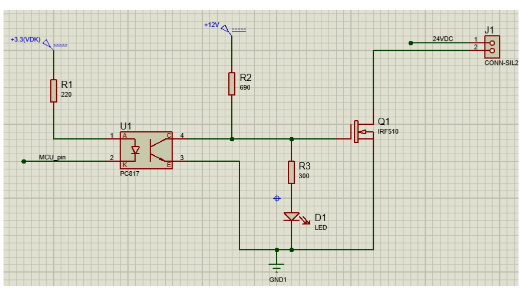


MCU

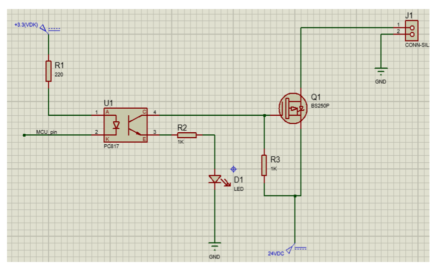


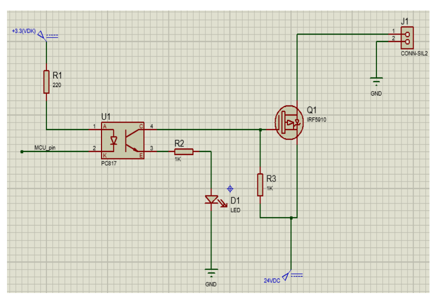
DO (NPN)



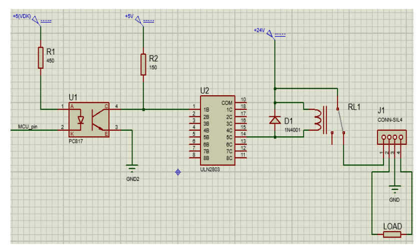


DO (PNP)

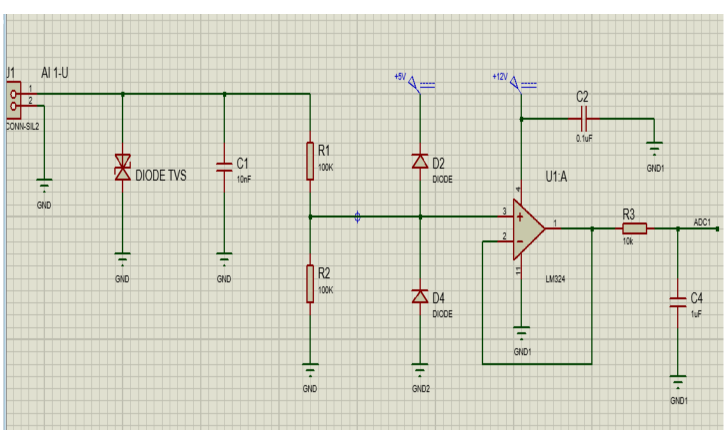




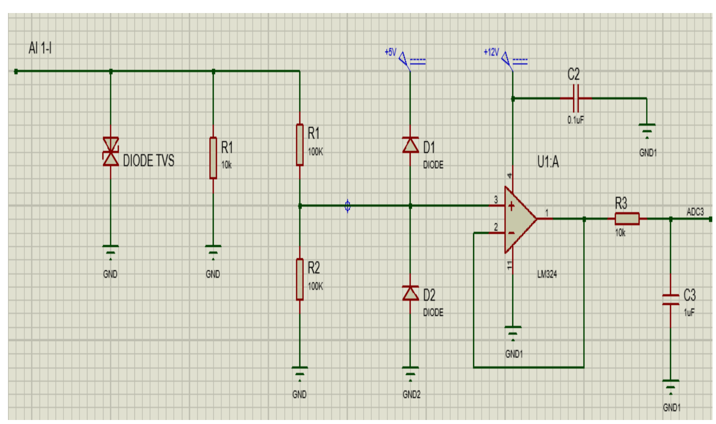
DO(Relay)



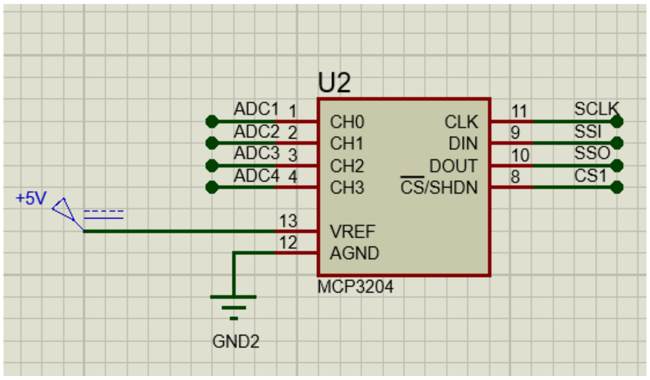
AI 0-10V



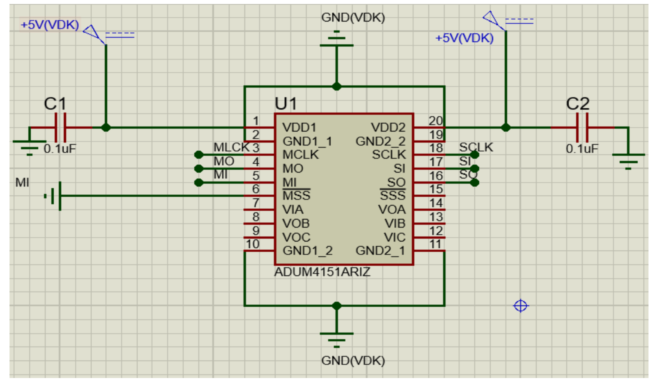
AI 4-20mA



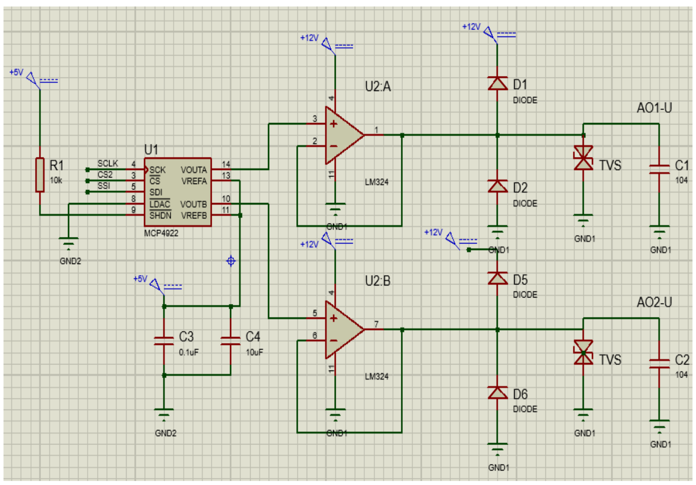
ADC



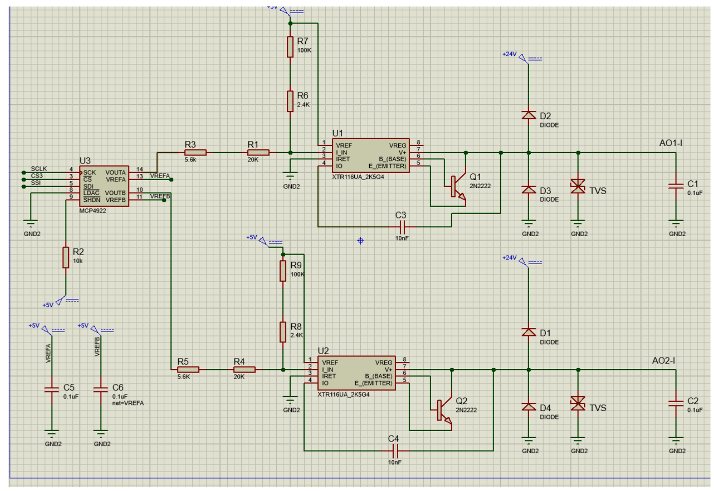
Isolation SPI



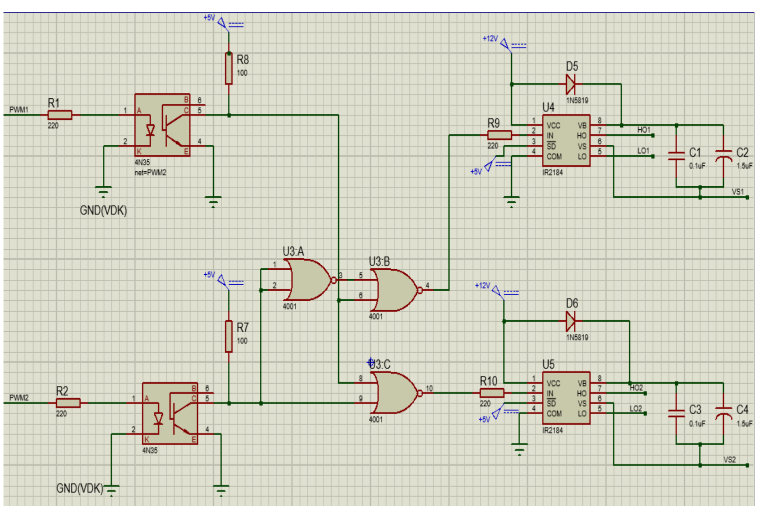
AO type voltage

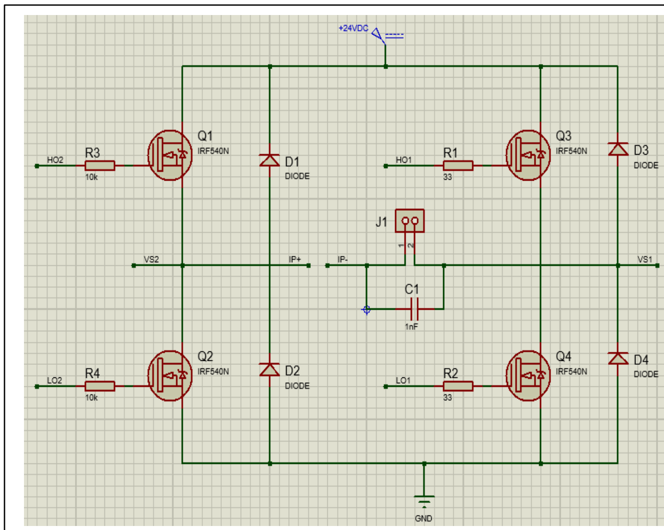


AO type current

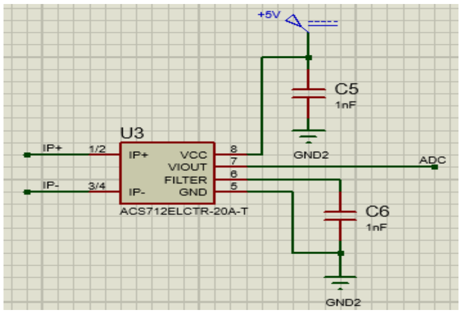


H brigde

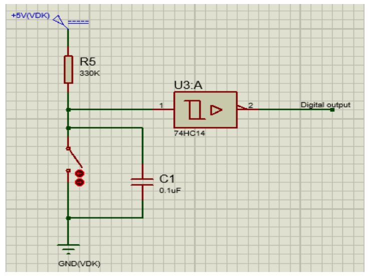




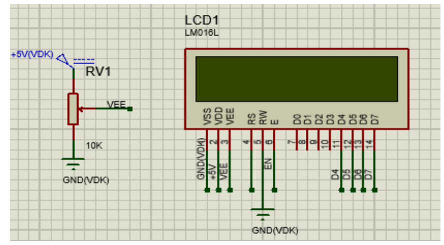
Measure current



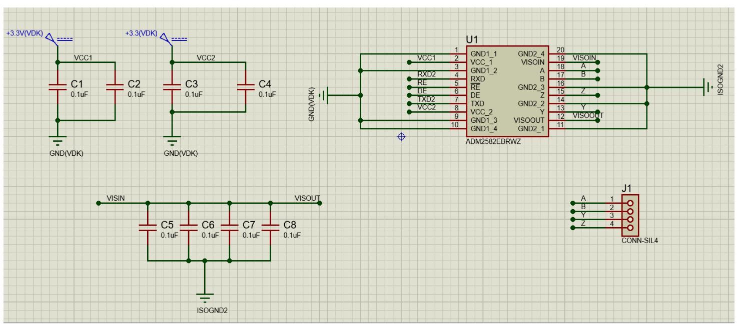
Button



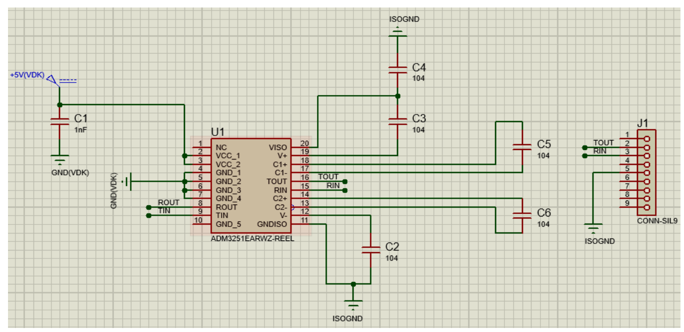
LCD



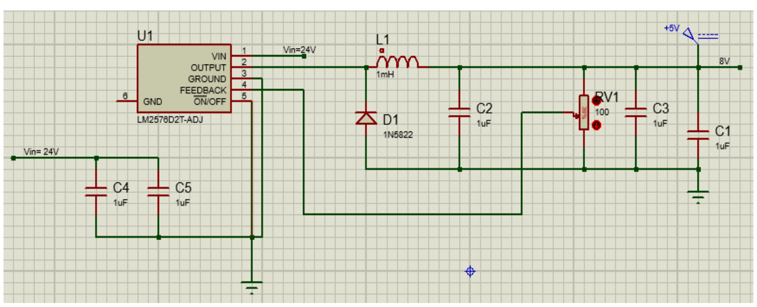
RS485



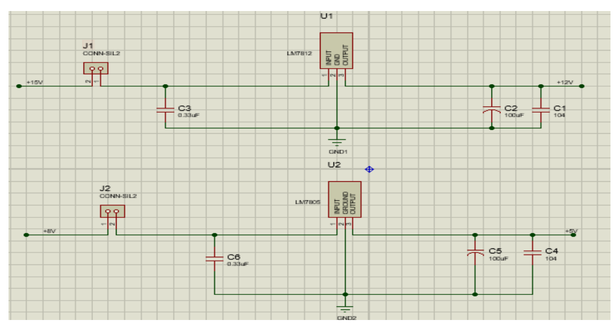
RS232



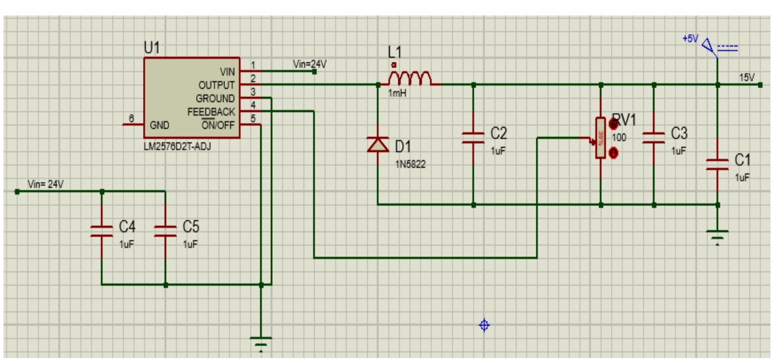
Power



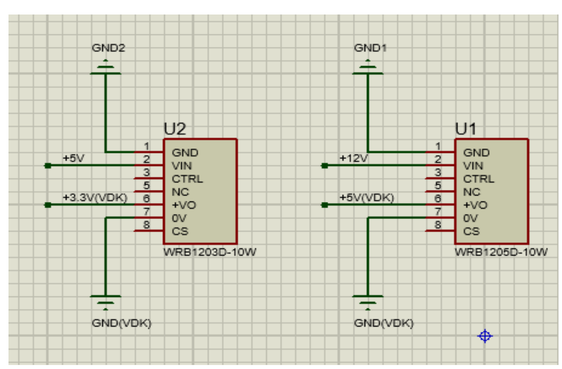
Power



Power



Isolating power IC



III. Selected solution

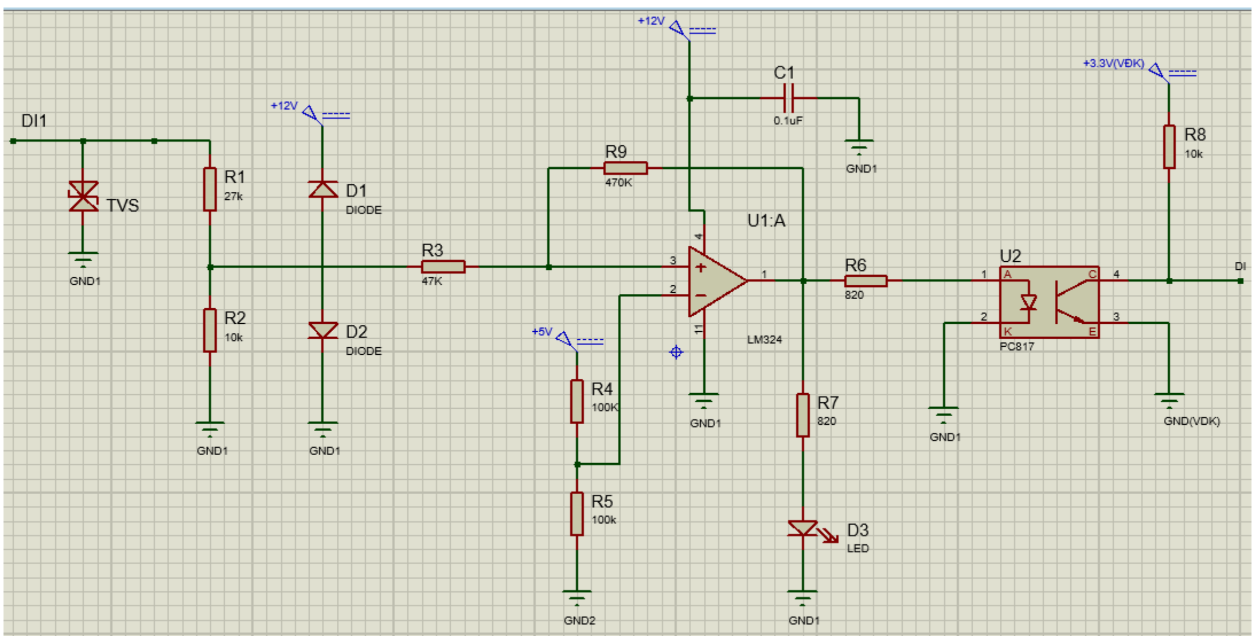
3.1. Digital input (DI)

a. Design Request:

- The input voltage corresponding to logic level 1 has a wide range: 10 – 36 VDC
- Isolation with microcontroller.
- Have input high voltage, low voltage and ESD protection

b. Method

- To ensure the logic level requirement, we need a voltage divider and Trigger-Smith circuit => use OPAM (Choose LM324 with power supply 12V)
- Use Optocouple to isolate between the digital input and the microcontroller.



c. Caculate

- Resistor of voltage divider circuit R1,R2.

Because the high logic voltage input to the voltage divider has a wide range (10-36V), we choose the resistor voltage divider circuit so that the maximum voltage on the P-pin of OPAM LM 324 is 10VDC.

We have : $V_P = \frac{R_2}{R_1+R_2} V_{DI} \le 10V$

But $V_{DI} = 10 \div 36V => \frac{R_2}{R_1+R_2} \le \frac{10}{36}$

$$=> R_1 \ge 2.6R_2$$

So choose $R_1 = 27k\Omega$ và $R_2 = 10k\Omega$

- Resistor of Trigger-Smith circuit $R_3, R_{4,} R_5, R_9$.

V_{cc} is positive voltage source for LM324 , chose $V_{cc} = 12V$.

Choose $\Delta V+ \approx \frac{V_{cc}}{10} = 1.2V => \frac{R_3}{R_3+R_9} \approx 0.1$

So choose $R_3 = 47K\Omega\, , R_9 = 470K\Omega$

Otherwhile , with DI voltage = 10V then the output of the Trigger-Smith circuit must still go high.

When $V_{DI} = 10V => V_P = \frac{R_2}{R_1+R_2} V_{DI} = \frac{10}{27+10} . 10 = 2.7V$

=> $V_N < 2.7V$

=> $V_N = \frac{R_5}{R_4+R_5} . V_{ref} < 2.7V$

$V_{ref} = 5V$, suy ra $V_N = \frac{R_5}{R_4+R_5} . 5 < 2.7V$

=>$\frac{R_5}{R_4} < 1.174$

So choose $R_4 = R_5 = 100k\Omega$

- **Resistor $\boldsymbol{R_6, R_7, R_8}$ *cho* PC817 ,Led và LM234**.

With Trigger-Smith circuit using amplification algorithm LM324 have $V_{cc} = 12V$, we have:

$$V_P > V_N \Rightarrow V_{out} = +V_{cc} - 1.5V = 10.5V$$

$$V_N > V_P \Rightarrow V_{out} = -V_{cc} = 0\text{V}$$

When DI input active (10-36V), $V_{out} = 10.5V$, there is current flowing through the LED to make the LED light, then:

$$I_{Led} = \frac{V_{cc} - U_{Led}}{R_7} \ and \ \ U_{led} = 1.8 \div 2.5V$$

Choose R_7 to current through the LED $I_{Led} = 9 \div 15mA$

Therefore: $$10mA \leq \frac{V_{cc}-U_{Led}}{R_7} \leq 12mA$$

$$=> \frac{10.5 - 1.8}{15\ mA} \leq R_7 \leq \frac{10.5 - 2.5}{9\ mA}$$
$$=> 580\Omega \leq R_7 \leq 889\Omega$$

So choose $R_7 = 820\Omega$.

Otherwise, $V_{out} = 10.5V$, current through R6 and PC817 (I_F) make the LED light , then:

$$I_F = \frac{V_{cc}-U_F}{R_6} \ và\ U_F = 1.2 \div 1.4V$$

Choose R_6 to current $I_F = 10 \div 15\ mA$

Therefore : $$10mA \leq \frac{V_{cc}-U_F}{R_6} \leq 15\ mA$$

$$=> \frac{10.5 - 1.4}{15\ mA} \leq R_6 \leq \frac{10.5 - 1.2}{10\ mA}$$
$$=> 606.67\Omega \leq R_6 \leq 930\Omega$$

So choose $R_6 = 820\ \Omega$

Choose $R_8 = 10\ k\Omega$: resistor R_8 to limit the current to the microcontroller when the PC817 locks and limit the current to terminal C of PC817.

- **Diode $\boldsymbol{D_1, D_2}$**:

Used to protect input high or low voltage:

+ High voltage: When the OPAM's non-inverting vacuum input voltage is greater than 12.6 V=> $V_{D1} \geq 0.6\,V$ $=> D_1$ guide.

⇨ Input voltage of OPAM max : 12.6 V

+ Low voltage : When input voltage is less than -0.6 V => $V_{D2} \geq 0.6\,V$ => D_2 guide

⇨ Input voltage OPAM min : -0.6 V

So choose Diode M7 1N4007 :

- Current : 1A
- Maximum DC blocking voltage: 1000V
- Maximum reverse current : 5uA

- Diode TVS : Protect sensitive electronic equipment from voltage transients induced lighting and other transient voltage events. The TVS diode is selected based on: working voltage , breakdown voltage , power. Because input voltage is 10-36V so:

⇨ Choose diode 1.5KE47A has:

- Working voltage : 40.2 V
- Breakdown voltage: 44.7V
- Max power: 1500W

3.2. Digital output (DO) (H=24V, L=0V)

a. Design Request:

- Isolation with microcontroller.
- Use with 24V DC voltage
- Have input high voltage, low voltage and ESD protection

b. Method:

- Use Opto-coupler to isolate between the digital output and microcontroller.
- Digital output have 3 type:

+ DO NPN

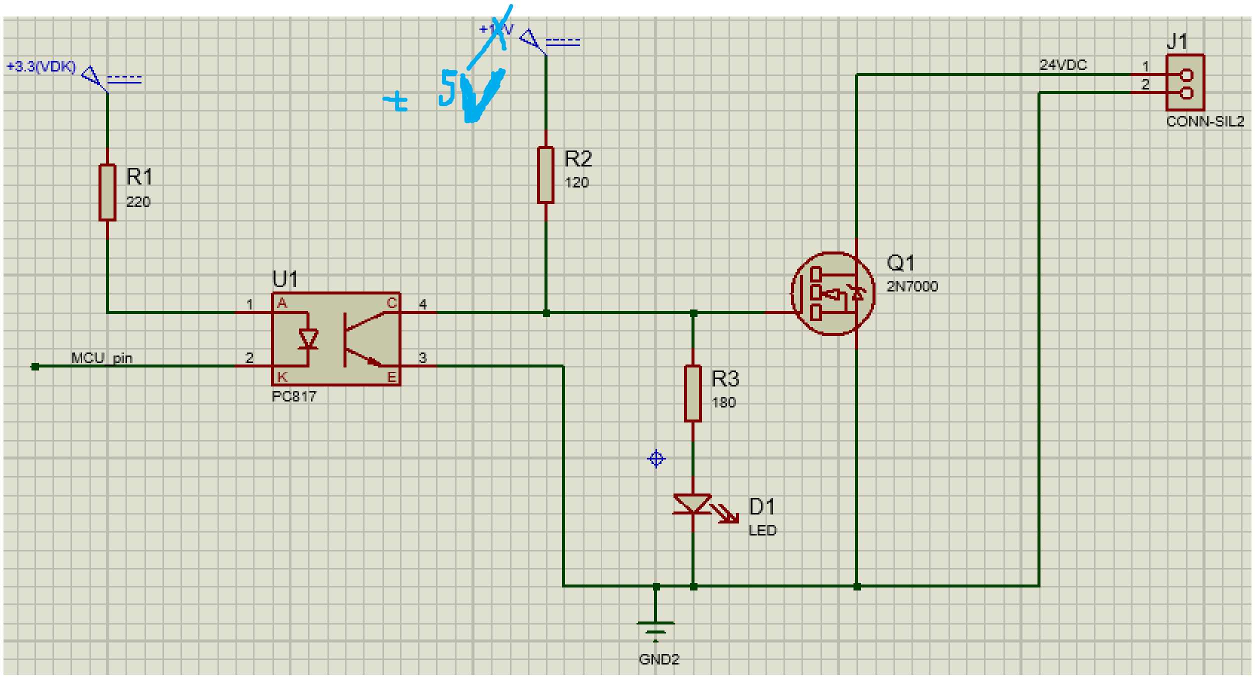
+ DO PNP

+ DO Relay.

3.2.1. DO type NPN

Method: Use Opto-coupler and Mosfet

- Low power : Use Mosfet 2N7000 because drain current continuous $I_D = 200mA$, pulsed $I_{DM} = 500mA$



- Choose R_1.

Request current for PC817 from 5-20mA.

We choose : $6mA \le I_{R1} \le 10mA$

Follow datasheet PC817:

Parameter	Symbol	Condition	MIN.	TYP.	MAX.	Unit
Forward voltage	V_F	I_F=20mA	-	1.2	1.4	V

$U_{AK} = 1.2 \rightarrow 1.4V => 3.3V - 0.4V - 1.4V \le U_{R1} \le 3.3V - 1.2V$

$=> 1.5V \le U_{R1} \le 2.1V$

$=> \frac{2.1V}{10mA} \le R_1 \le \frac{1.5V}{6mA}$

=> $210\Omega \leq R_1 \leq 250\Omega$

So choose $R_1 = 220\Omega$

- Choose R_2, R_3.

When PC817 guide: follow datasheet PC817 , $I_c \leq 50mA$

=>$\frac{5V}{R_2} < 50mA$ => $R_2 > 100\Omega$ (*)

When PC817 block:

Parameter	Symbol	Test Conditions	Typ[a]	Min	Max	Min	Max	Unit
Static								
Drain-Source Breakdown Voltage	$V_{(BR)DSS}$	$V_{GS} = 0$ V, $I_D = 10\ \mu A$	70	60		60		V
Gate-Threshold Voltage	$V_{GS(th)}$	$V_{DS} = V_{GS}$, $I_D = 1$ mA	2.1	0.8	3			
		$V_{DS} = V_{GS}$, $I_D = 0.25$ mA	2.0			1	2.5	

To activate the Mosfet, the voltage applied to the G terminal must be at least 3V. Choose the value R_3 so that the voltage $3.3 \leq U_{GS} < 5V$ (5V is the voltage supplied to the Collector terminal of PC817) and current flows through the LED $I_{Led} = 10mA$.

Voltage drop on Led 1.8 - 2.5V=> $1.5V \leq U_{R3} \leq 2.5V$

=>$\frac{1.5V}{10mA} \leq R_3 \leq \frac{2.5V}{10mA}$ => $150 \leq R_3 \leq 250$ => choose $R_3 = 180\Omega$.

Because $R_3 = 180\Omega$. So $U_{R3} = 180x10x10^{-3} = 1.8V$

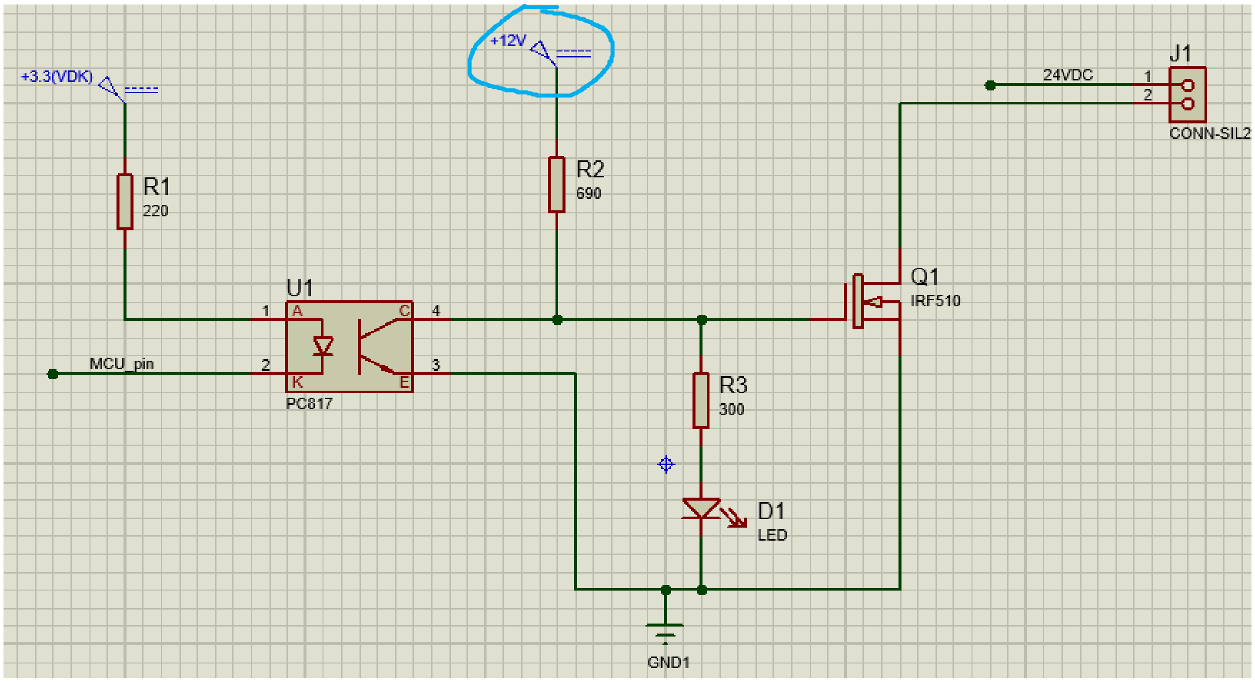
=>$3.6V \leq U_{R3} + U_{Led} \leq 4.3V$

=>$0.7V \leq U_{R2} \leq 1.4V$

=>$\frac{0.7V}{10mA} \leq R_2 \leq \frac{1.4V}{10mA}$ => $70\Omega \leq R_2 \leq 140\Omega$ (**)

From (*),(**) choose $R_2 = 120\Omega$

- High power : Use Mosfet IFR510 because drain current continuous $I_D = 5.6A$, pulsed $I_{DM} = 20A$



- Choose $R_1 = 220\Omega$ as calculate above
- Choose R_2, R_3

When PC817 guide: follow datasheet PC817 , $I_c \leq 50mA$

=>$\frac{12V}{R_2} < 50mA$ => $R_2 > 240\ \Omega$ (1)

When PC817 block:

SPECIFICATIONS (T_J = 25 °C, unless otherwise noted)						
PARAMETER	**SYMBOL**	**TEST CONDITIONS**	**MIN.**	**TYP.**	**MAX.**	**UNIT**
Static						
Drain-Source Breakdown Voltage	V_{DS}	V_{GS} = 0 V, I_D = 250 μA	100	-	-	V
V_{DS} Temperature Coefficient	$\Delta V_{DS}/T_J$	Reference to 25 °C, I_D = 1 mA	-	0.12	-	V/°C
Gate-Source Threshold Voltage	$V_{GS(th)}$	V_{DS} = V_{GS}, I_D = 250 μA	2.0	-	4.0	V
Gate-Source Leakage	I_{GSS}	V_{GS} = ± 20 V	-	-	± 100	nA

To activate the Mosfet, the voltage applied to the G terminal must be at least 4V. Choose the value R3 so that the voltage $4.5 \leq U_{GS} < 12V$ and current flows through the LED $I_{Led} = 10mA$.

Voltage drop on Led $1.8 \rightarrow 2.5V$ => $2.7 \leq U_{R3} \leq 9.5V$

=>$\frac{2.7V}{10mA} \leq R_3 \leq \frac{9.5V}{10mA}$ => $270 \leq R_3 \leq 950\Omega$ => Choose $R_3 = 300\Omega$

So $R_3 = 300\Omega$ so $U_{R3} = 300x10x10^{-3} = 3V$

=>$4.8 \leq U_{R3} + U_{Led} \leq 5.5V$

=>$6.5 \leq U_{R2} \leq 7.2V$

=>$\frac{6.5V}{10mA} \leq R_2 \leq \frac{7.2V}{10mA} => 650 \leq R_2 \leq 720\ \Omega$ (2)

From (1), (2) we choose $R_2 = 690\ \Omega$.

*Principle: When the output of the microcontroller (MCU_Pin) is low (0-0.4V), the infrared led in PC817 light, Transistor leads to saturation, current goes from positive source through poles C and E to ground. Head to the Mosfet low, load open circuit.

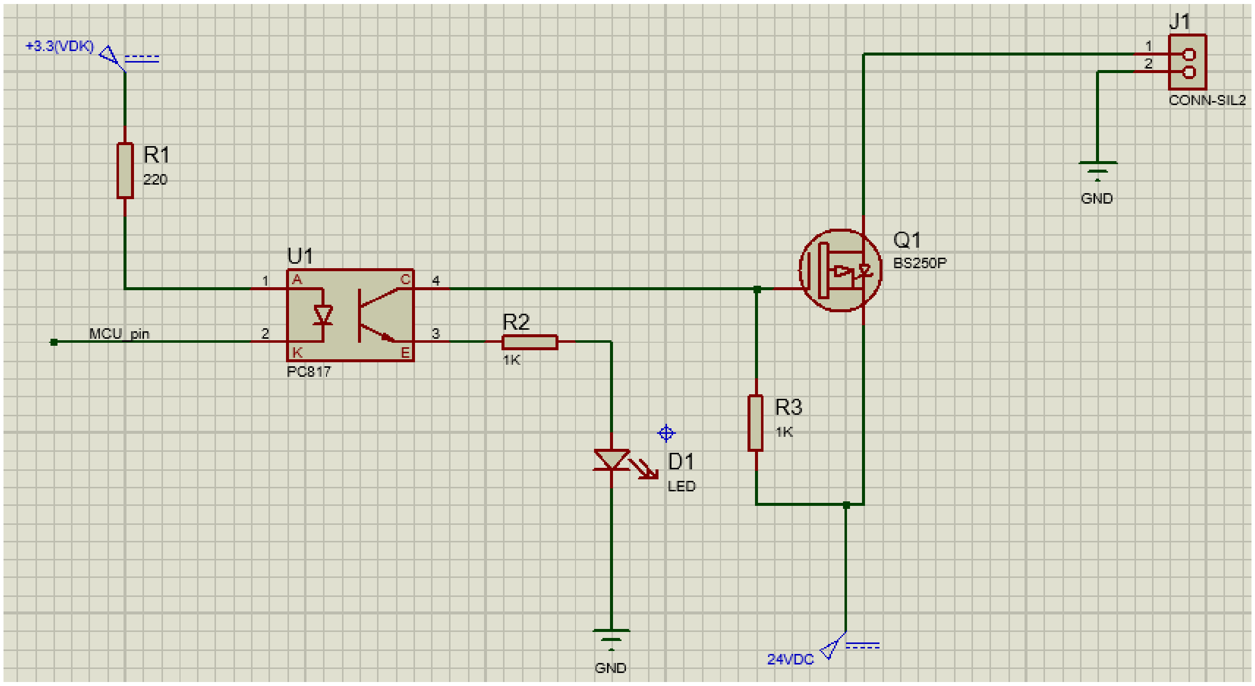
When output MCU_Pin goes high (size 2.4V), infrared led does not light, Transistor locks, current goes from the positive part of the source to the positive part of the Mosfet, allowing the load to operate. Still 1 part will go through led D1 to signal that the DO output is having power.

3.2.2. DO type PNP

Method use IC PC817 and Mosfet.

For PNP DO output we use BS250P equivalent to 2N7000 and IRF9510 equivalent to IRF510 but P-Mosfet.

- Use Mosfet BS250P:



Principle:

+ When the microcontroller output (MCU_Pin) is low (0-0.4V), the infrared led in PC817 is bright, Transistor leads to saturation, current goes from positive 24V source to pole C and Led to ground. Then the P-Mosfet conducts current and supplies power to the load output at the same time the Led bright.

+ When the output MCU_Pin goes high (size 2.4V), infrared led does not light, Transistor locks, resistor R3 does not conduct current, but pulls the voltage of the G terminal of the Mosfet to 24V, Mosfet lock, output open circuit.

Caculate conponents:

- Choose $R_1 = 220\Omega$ the same DO type NPN.
- Choose R_2, R_3.

R3 is used to suspend the G terminal voltage to 24V when the PC817 is not conducting. R2, R3 are used to limit the current electricity flows through the Led, and at the same time a voltage applied to the G terminal of the Mosfet to activate the Mosfet.

When PC817 guide: choose R2,R3 to current through LED from 10-12mA.

Voltage drop on Led 1.8-2.5V, saturation voltage C, E of PC817 is

Uce ≤0.2 V. So $21.3V \leq U_{r2} + U_{R3} \leq 22.2V$

$$10mA \leq I_{Led} \leq 12mA$$

- ⇨ $\frac{22.2V}{12mA} \leq R_2 + R_3 \leq \frac{21.3V}{10mA}$ => $1850 \leq R_2 + R_3 \leq 2130\Omega$
- ⇨ Choose R2=R3=1K.

Replace the opposite, R2=R3=1$K\Omega$ => $10.65 \leq I_{Led} \leq 11.1mA$

- ⇨ $10.65 \leq U_{R3} \leq 11.1V$
- ⇨ $-11.1 \leq U_{GS} \leq -10.65V$

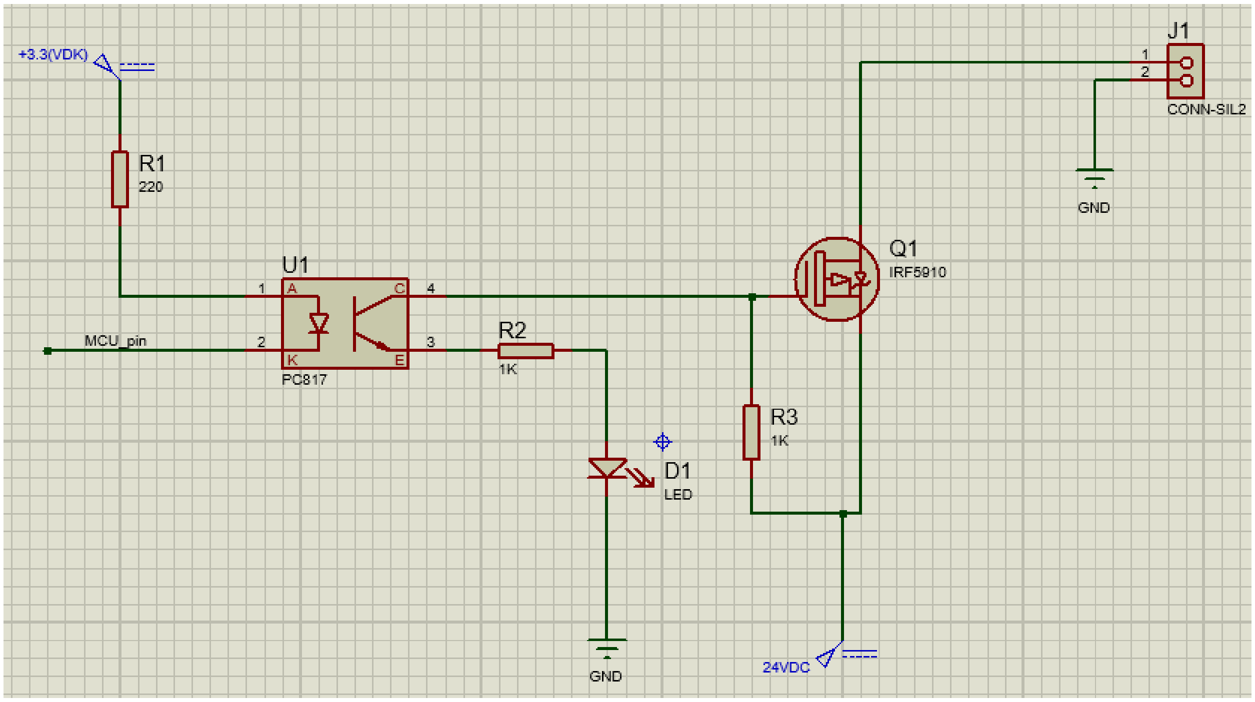
Follow datasheet BS250P:

PARAMETER	SYMBOL	VALUE	UNIT
Drain-Source Voltage	V_{DS}	-45	V
Continuous Drain Current at T_{amb}=25°C	I_D	-230	mA
Pulsed Drain Current	I_{DM}	-3	A
Gate-Source Voltage	V_{GS}	±20	V
Power Dissipation at T_{amb}=25°C	P_{tot}	700	mW

$$U_{Gs,th} = -3.5V \Rightarrow Mosfet\ open$$

$$U_{GS,max} = -20V \Rightarrow R_2, R_3 value\ is\ accept$$

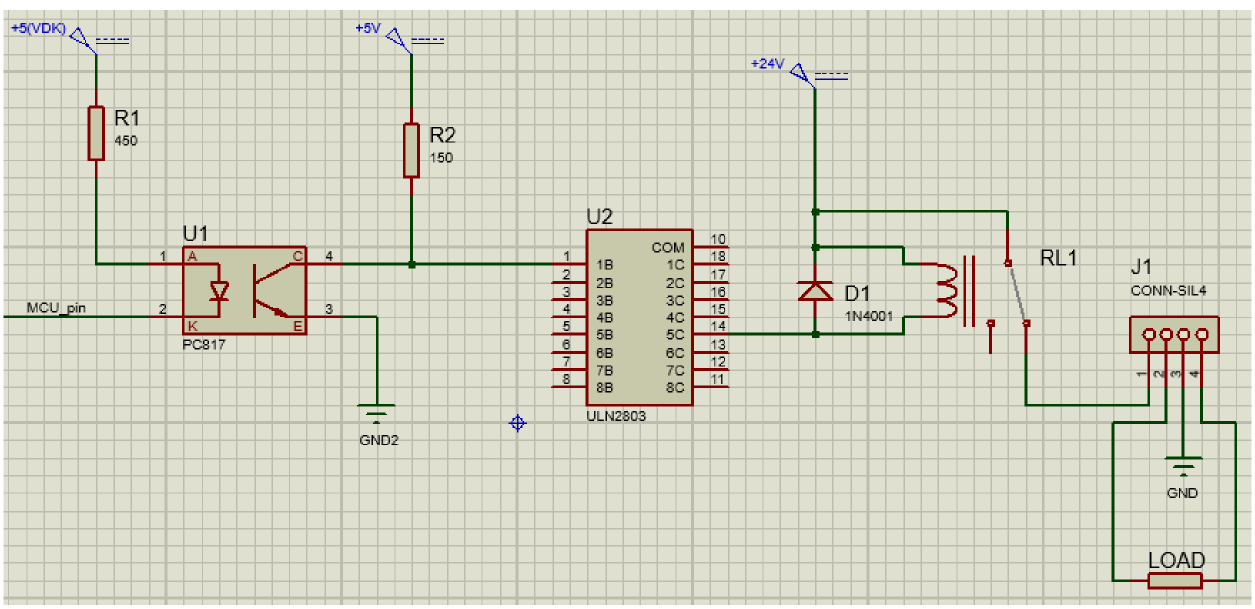
- Use Mosfet IRF9510



In principle, calculation and selection of the same resistor values as Mosfet BS250P.

3.2.3. DO type relay

Method: Use PC817 and IC ULN2803.



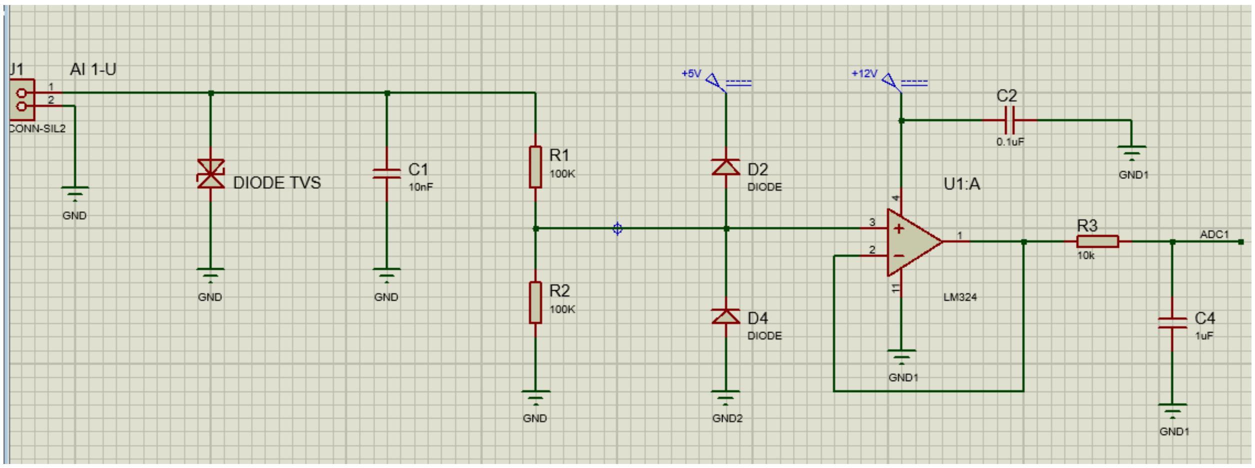
3.3. Analog Input (AI)

a. Design Request:

- Input voltage 0-10V, input current 4-20mA
- Isolation with microcontroller
- Have input high voltage, low voltage and ESD protection
- Can receive analog set signal
- Have input filter

b. Method: Use ADC

3.3.1.Input voltage 0-10V



- Caculate R1,R2:

Because input voltage AI is 0-10V , input voltage ADC is 0-5V:

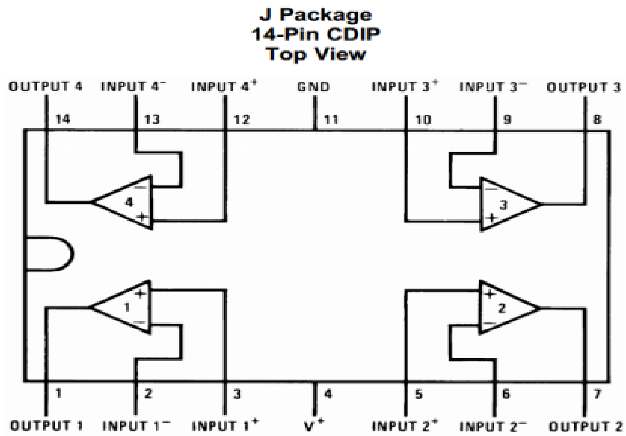
Choose voltage divider circuit: $R_1 = R_2 = 100K\Omega$ to input current small ($I_{Vmax} = \frac{10}{200k\Omega} = 50uA$) => Reduce losses and reduce voltage drop on the line.

- OPAM:

OPAM is used to repeat voltage 0-5V. Because the circuit only uses a single circuit. OPAM selection has voltage ≈ earth voltage.

Choose OPAM LM324 has :

- Wide power supply range Single supply : $3V_{DC}\ to\ 30V_{DC}$
- Wide power supply range Dual supply: $\pm 1.5V_{DC}\ to\ \pm 15V_{DC}$
- Large output voltage : $0V_{DC}\ to\ V_{CC} - 1.5V_{DC}$ swing



- Low pass filter circuit RC:

Select cutoff frequency is 100Hz

=>$\omega_c = \frac{1}{R_3 C_4} = 100Hz$. Choose R_3=10K => C_4=1uF

- Diode D_2, D_4:

Used to protect input high voltage and low voltage:

+ High voltage: When input voltage is greater than 11.2 V=> $V_{D2} \geq 0.6\,V$ $=> D_2$ guide.

⇨ Input voltage of OPAM max : 5.6 V

+ Low voltage : When input voltage is less than -1.2 V => $V_{D4} \geq 0.6\,V$ => D_4 guide

⇨ Input voltage OPAM min : -0.6 V

So choose Diode M7 1N4007 :

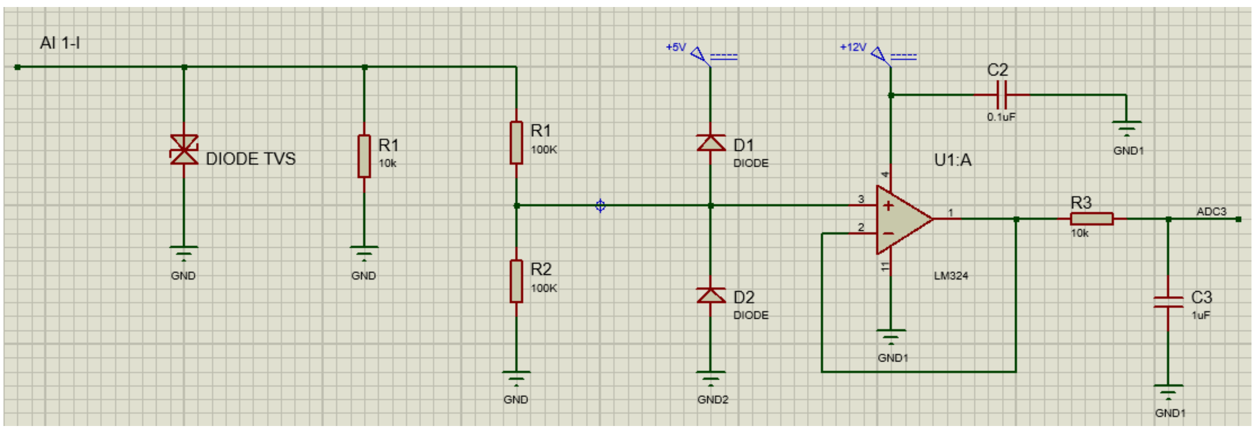
- Current : 1A
- Maximum DC blocking voltage: 1000V
- Maximum reverse current : 5uA
- Diode TVS : Protect sensitive electronic equipment from voltage transients induced lighting and other transient voltage events. The

TVS diode is selected based on: working voltage , breakdown voltage , power. Because input voltage is 0-10V so:

⇨ Choose diode 1.5KE15A has:

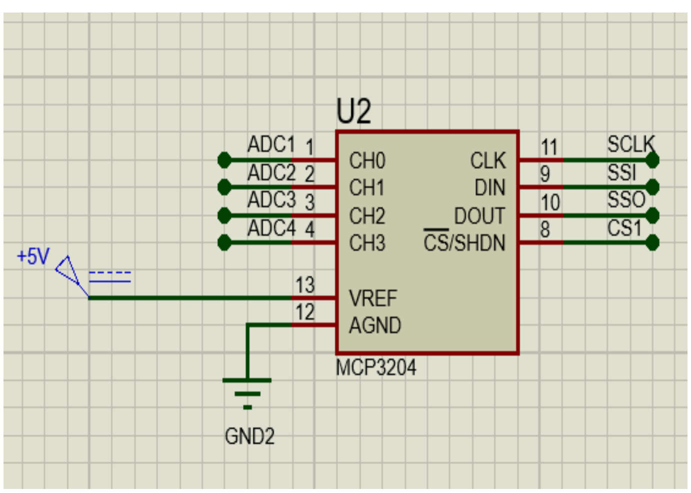
- Working voltage : 12.8 V
- Current at working voltage: 1uA
- Breakdown voltage: 15V
- Max power: 1500W

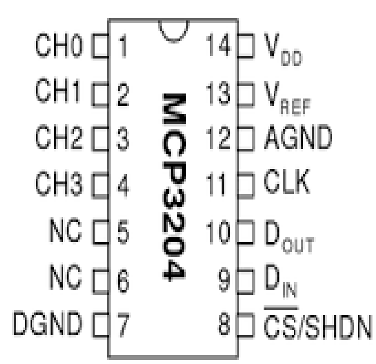
3.3.2. Input current 4-20mA



Input current 4-20mA passing through resistor R1=220Ω generates voltage 0.88 – 4.4 V . Other components are selected as AI voltage.

- ADC : Choose ADC: MCP2304





+ ADC 12 bit resolution

+ 4 input channels

+ SPI serial interface (mode 0.0 and 1,1)

+ Single supply operation : 2.7V – 5.5V

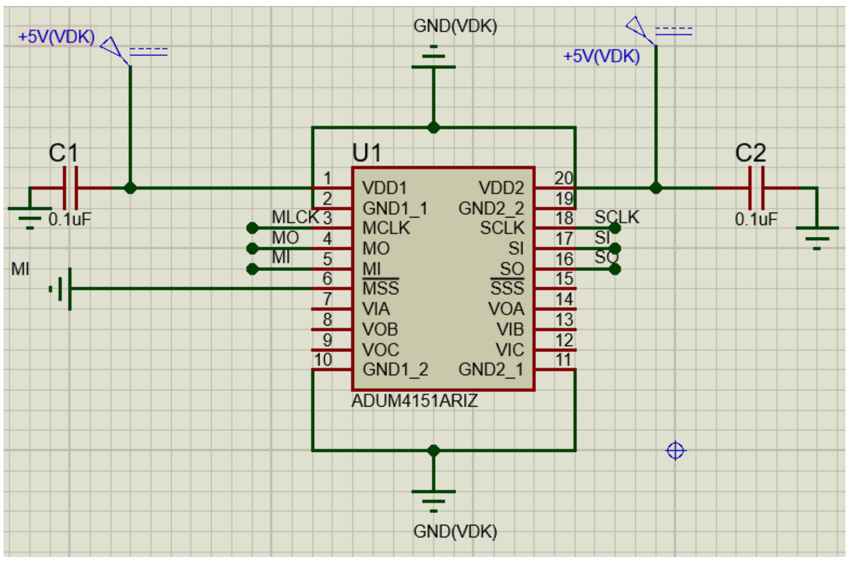
+ 100ksps max sampling rate at $V_{DD} = 5V$

+ 50ksps max sampling rate at $V_{DD} = 2.7V$

ADC for 2 analog inputs 0-10V, 2 analog inputs 4-20mA

- Isolation SPI:

Because we need to transmit information with high speed and reliability, we choose IC ADUM4154 of Analog Devices



ADUM4154:

- Supports up to 17MHz SPI clock speed
- 4 high speed, low propagation delay , SPI signal isolation channels
- Supports up to 4 slave devices
- High temperature operation: $125°C$
- Working voltage: 3.3/5V

Pin SCLK, SI, SO,SSO of ADUM4154 connect ADC MCP3204

Pin MCLK, MO,MI,SSAO,SSA1 of ADUM4154 connect microcontroller.

Capacitor $C_{15} = C_{16} = 0.1uF$ has the effect of filtering high-frequency waves caused by other components on the circuit.

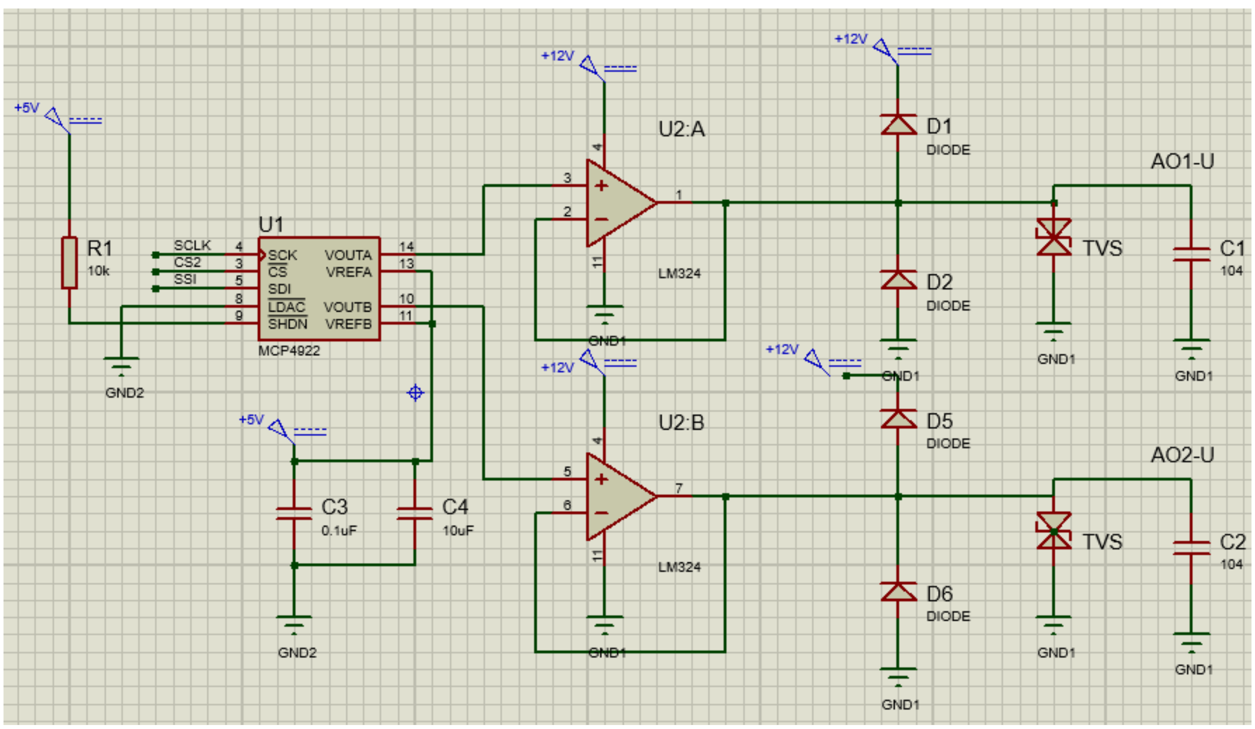
3.4. **Analog output (AO)**

3.4.1. AO type Voltage

a. Design Reques:

- Output voltage : 0-10 V
- Isolation with microcontroller
- Protection Output voltage
- Protection ESD

b. Method : Use DAC



- DAC : Choose DAC MCP4922

+ 12-Bit Resolution

+ SPI Interface with 20MHZ Clock Support

+ Fast Setting Time of 4.5 μs

+ Selectable Unity or 2x gain output

+ 450 kHz Multiplier Mode

+ 2.7V to 5.5V Single supply operation

+ Extended Temperature Range :$-40°C\ to + 125°C$

- Choose 2x gain output voltage of MCP4922 to output voltage of DAC is: 0-10V.
- SPI isolation using the same AduM4154 IC with Analog Input.
- To maximize the output current, we use a voltage repeater.

Output current of LM324:

Output Current	Source	$V_O = 2$ V	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$	10	20	10	20	10	20	mA
	Sink		$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$	10	15	5	8	5	8	

⇨ $I_{Sourcetyp} = 20\ mA$
⇨ $I_{Sinktyp} = 8\ mA$

- **Diode D_1, D_2, D_5, D_6 :**

Used to protect input high voltage and low voltage:

+ High voltage: When input voltage is greater than 11.2 V=> $V_{D1} \geq 5.6\ V$ => D_2 guide.

⇨ Input voltage of OPAM max : 5.6 V

+ Low voltage : When input voltage is less than -1.2 V => $V_{D4} \geq 0.6\ V$ => D_4 guide

⇨ Input voltage OPAM min : -0.6 V

So choose Diode M7 1N4007 :

- Current : 1A
- Maximum DC blocking voltage: 1000V
- Maximum reverse current : 5uA

- Diode TVS : Protect sensitive electronic equipment from voltage transients induced lighting and other transient voltage events. The TVS diode is selected based on: working voltage , breakdown voltage , power. Because output voltage is 0-10V so:

⇨ Choose diode 1.5KE15A has:
- Working voltage : 12.8 V
- Current at working voltage: 1uA
- Breakdown voltage: 15V
- Max power: 1500W

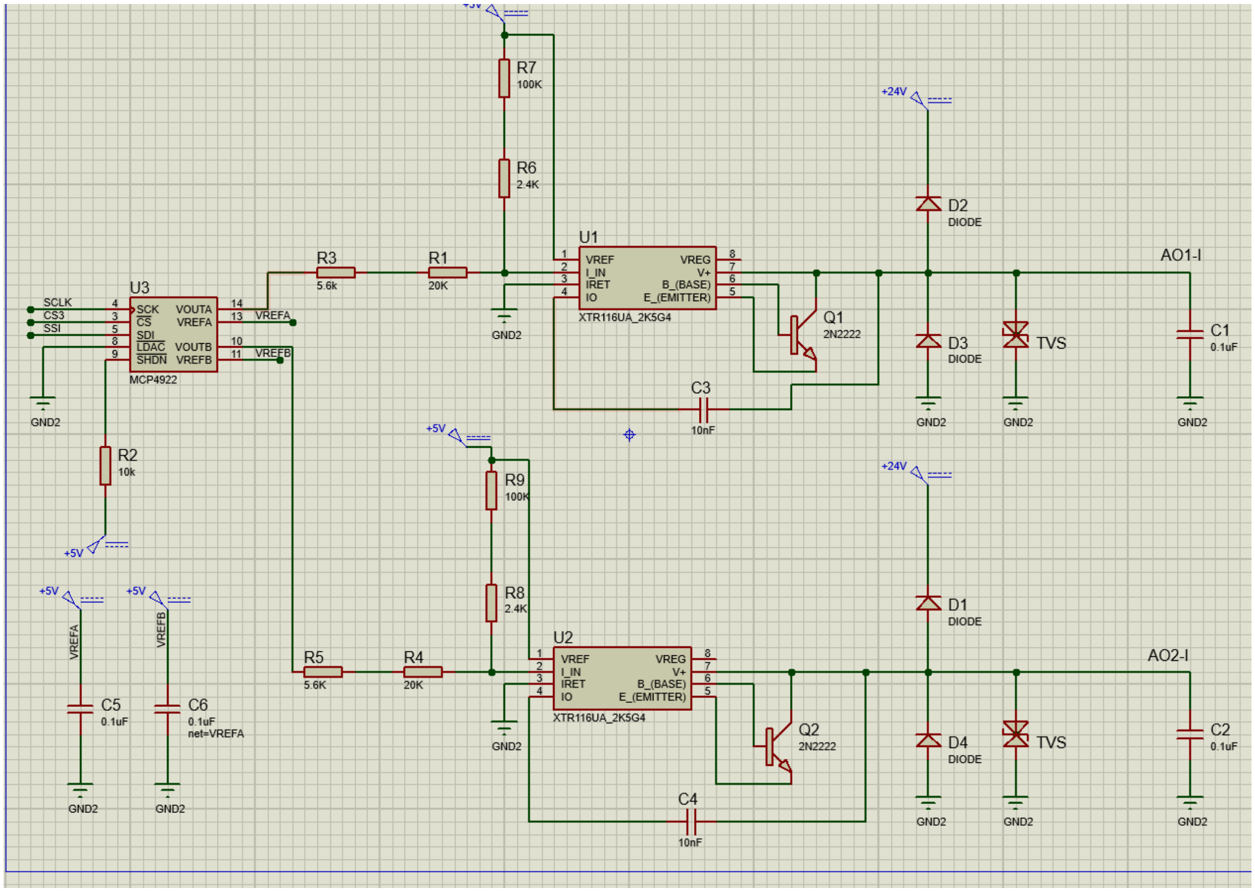
Capacitor $C_1 = C_2 = 0.1uF$: It has the effect of filtering high frequency waves from the outside.

Capacitor $C_3 = 0.1uF, C_4 = 10uF$: has the effect of filtering high-frequency waves caused by other components on the circuit and stabilizing circuit voltage.

3.4.2. AO type current

a. Design Reques:
- Output current : 4-20 mA
- Isolation with microcontroller
- Protection Input/Output voltage
- Protection ESD

b. Method : Use DAC + IC (create current source)



- DAC: Choose DAC MCP4922

  + 12-Bit Resolution

  + SPI Interface with 20MHZ Clock Support

  + Fast Setting Time of 4.5 μs

  + Selectable Unity or 2x gain output

  + 450 kHz Multiplier Mode

  + 2.7V to 5.5V Single supply operation

  + Extended Temperature Range :$-40°C\ to + 125°C$

Choose x1voltage mode of MCP4922 => output voltage of ADC is 0-5V

- Make current source 4-20mA:

Use IC XTR116U:

  - Low span error: 0.05%
  - Output current max: 25mA

    - Low nonlinearity error: 0.003%
    - Wide loop supply range: 7.5V to 36V
- Caculate resistor :

We have : Follow datasheet IC XTR116U $I_o = 100I_{in}$

Output current : $I_o = 4 \div 20mA$

=>$I_{in} = 40\mu A \div 200\mu A$

DAC use VREF = 4.096 V of IC XTR116U . To use the full output range 0-4.096V of DAC, we use resistors to generate offset current.

When $V_{DAC} = 0V$:

$$I_{in} = \frac{V_{REF}}{R_7 + R_6} = \frac{4.096}{R_7 + R_6} = 40\mu A$$

=>$R_7 + R_6 = 102.4\ K\Omega$

=>$R_7 = 100K\Omega, R_6 = 2.4K\Omega.$

When $V_{DAC} = 4.096V$:

$$I_{in} = \frac{V_{REF}}{R_7 + R_6} + \frac{V_{DAC}}{R_3 + R_1} = 200\mu A$$

=>$R_3 + R_1 = 25.6K\Omega$

=>$R_3 = 5.6K\Omega, R_1 = 20K\Omega.$

Capacitor C1= C2=0.1uF: It has the effect of filtering high frequency waves from the outside.

- Transistor:

Transistor fully tolerates the output current, so it is necessary to choose a transistor that can withstand 36V voltage and current 20mA.

Choose transistor 2N222:

- Voltage: $V_{CE} = 40\ VDC$

- ○ Current: $I_C = 600mA$
- Diode and Diode TVS are selected to be the same at voltage AO.

3.5. H bridge

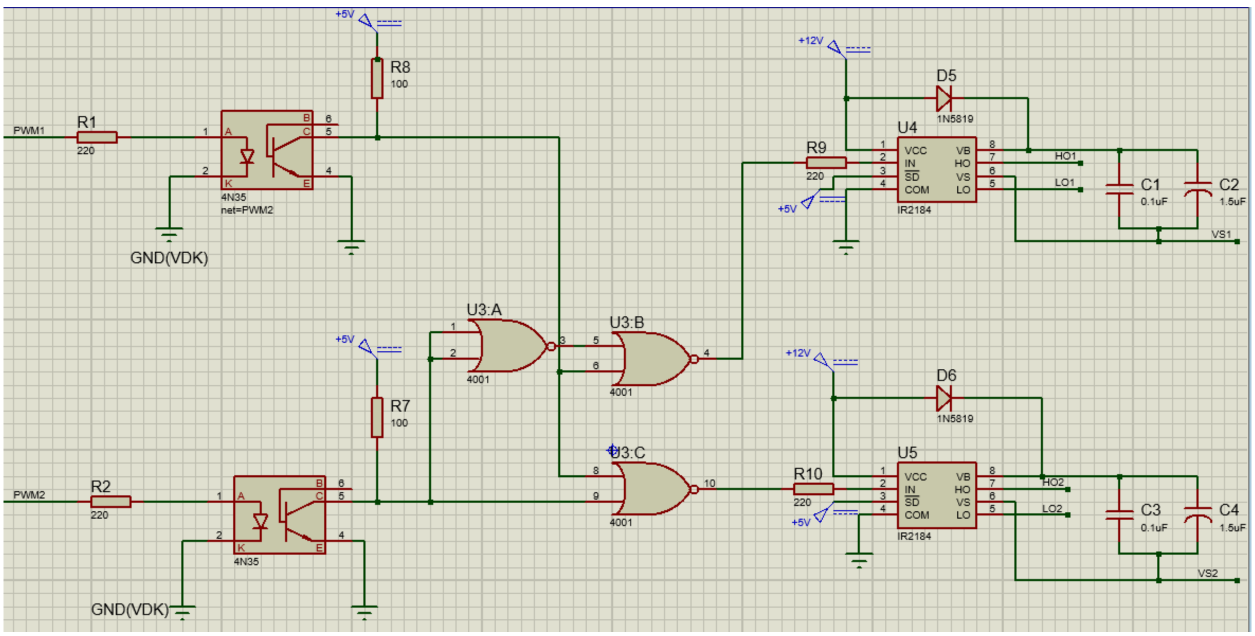
a. Design Request:

- $V_{DC} = 24V$
- $I_{MaxDC} = 20A$
- Isolation with microcontroller

b. Method :

Use Optocouple + Mosfet

- Using PWM pulse generation method to open and close the power supply Mosfet 24V and reversing for motor.
- Using Optocouple to isolate PWM pulses from Microcontroller and Driver of Mosfet



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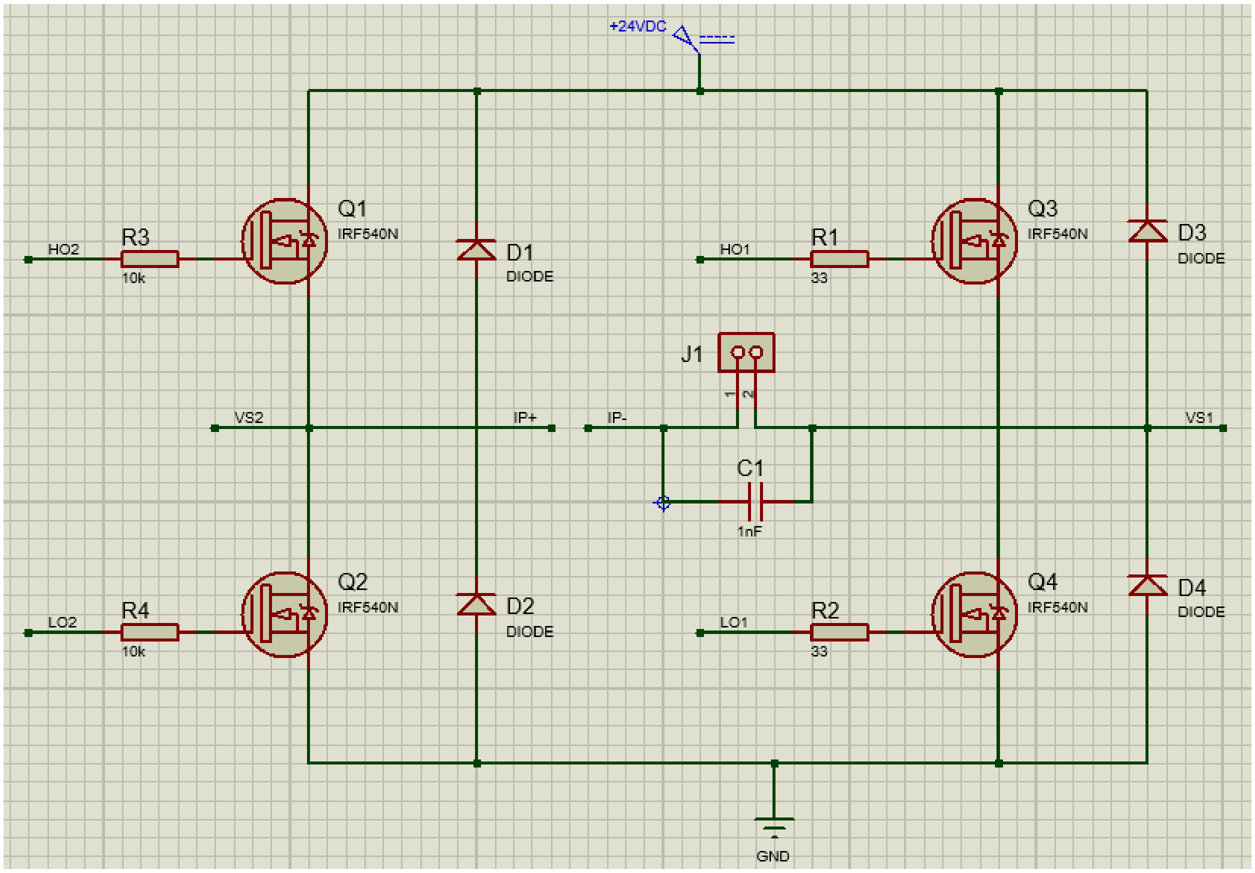


- Choose Mosfet :

From the design requirements, the voltage applied to the motor is 24V and the maximum current flowing through the motor is 20A.

⇨ Choose IRF540N have $U_{DSmax} = 100V\ and\ I_{Dmax} = 33A$

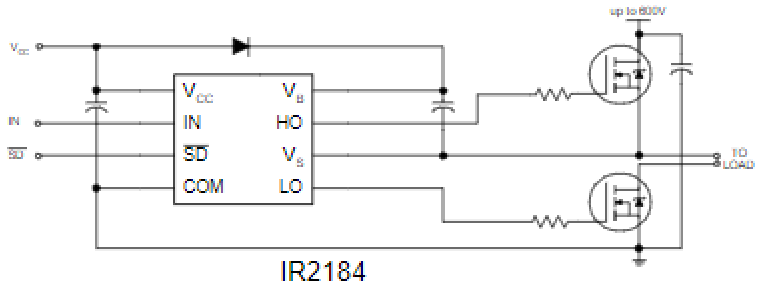
- Choose Driver for Mosfet IRF540N

Mosfet IRF540N, the voltage required to be applied to the G terminal is U_{GS} at least 10V for the FET to saturate.

⇨ Choose Driver : IR2184

Input/output current: 1.4A/1.8A

Output voltage control Mosfet : 10-20V



IR2184

- Caculate resistor , Diode for Driver cuicuit and H bridge
  - Diode $D_1 \div D_6$: Choose a high frequency response diode

=>choose Diode Schottky 1N5819(1A, 40V)

  - R_1, R_2, R_3, R_4 : Choose follow datasheet IR2184

Choose follow working temperature :

⇨ $R_1 = R_2 = R_3 = R_4 = 33\Omega$.

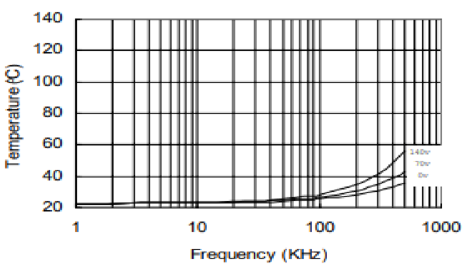


Figure 25. IR21814 vs. Frequency (IRFBC 20), R_{gate}=33Ω, V_{CC}=15V

  - R_9, R_{10}:

+ Mode 1: calculate input current max:

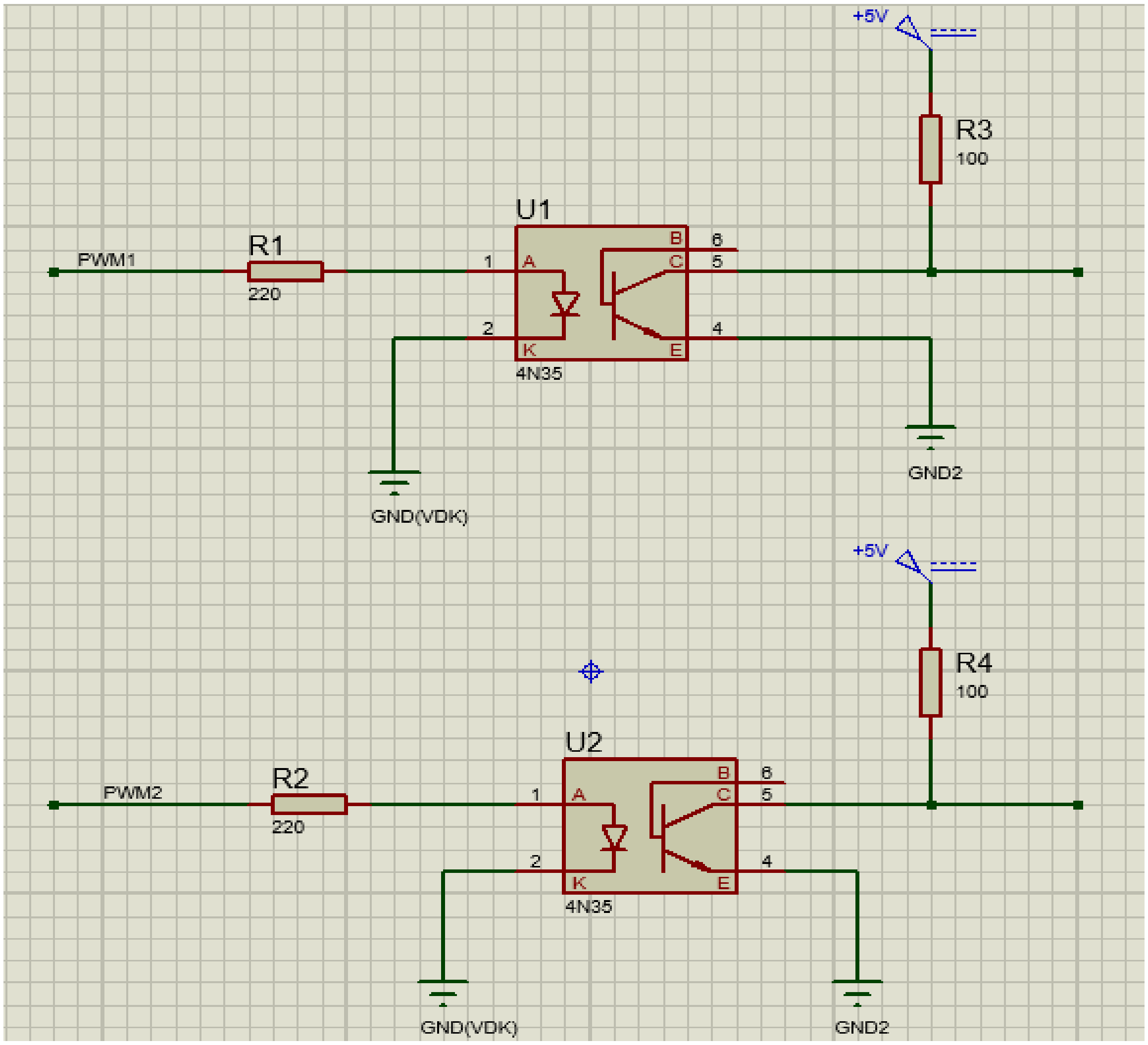
$$\frac{V_{10min} - V_{IH}}{I_{IN+max}} = \frac{4.95 - 2.7}{60.10^{-6}} = 37.5k\Omega$$

+ Mode 0:

$$\frac{V_{10min} - V_{IL}}{I_{IN-max}} = \frac{0.05 - 0}{10^{-6}} = 50k\Omega$$

Choose: $R_9 = R_{10} = 47k\Omega$

- Selection and calculation for optocoupler isolation circuit.



Choose Optocouple 4N35:

Turn–On Time	(I_C = 2 mA, V_{CC} = 10 V, R_L = 100 Ω)(3)	t_{on}	—	7.5	10	µs
Turn–Off Time		t_{off}	—	5.7	10	
Rise Time		t_r	—	3.2	—	
Fall Time		t_f	—	4.7	—	

=> Max working frequency: 50kHz – meet the output PWM pulse frequency for H-bridge circuit.

Caculate R1,R2:

Select the LED input current of the 4N35 to be 10 mA, the maximum voltage placed on the Led is $V_{Fmax} = 1.5V, V_{Fmin} = 0.8V$

$$R_1 = R_2 \geq \frac{3.3 - 1.5}{10.10^{-3}} = 180\Omega$$

VDC output current <= 12mA (when controlling Led of 8mA pins):

=>$\frac{3.3-V_{Fmin}}{10.10^{-3}} \leq 12mA$

=>$R \geq 208.33\Omega$

=>choose $R_1 = R_2 = 220\Omega$.

Caculate R3,R4:

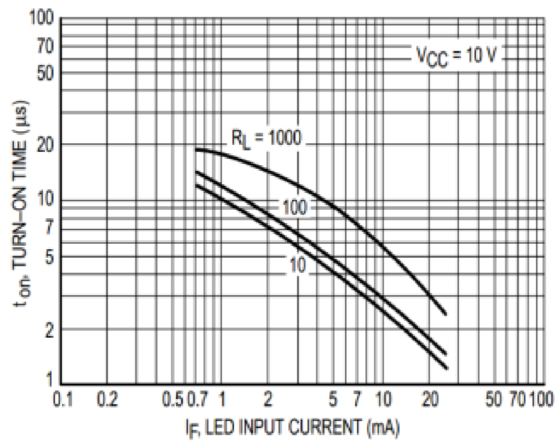


Figure 7. Turn–On Switching Times

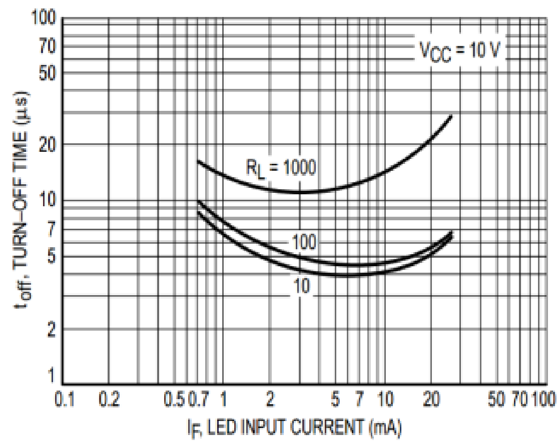


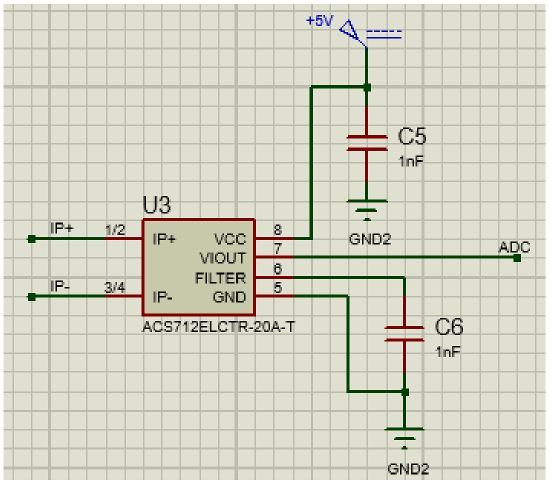
Figure 8. Turn–Off Switching Times

Choose $R_3 = R_4 = 100\Omega$

- Bootstrap capacitor.

3.6. Measure currnet

Use IC ACS712 – 20A .



Advantage:

+ Measure both AC and DC current

+ Electrical isolation

=> Feed directly to microcontroller ADC to increase sampling rate

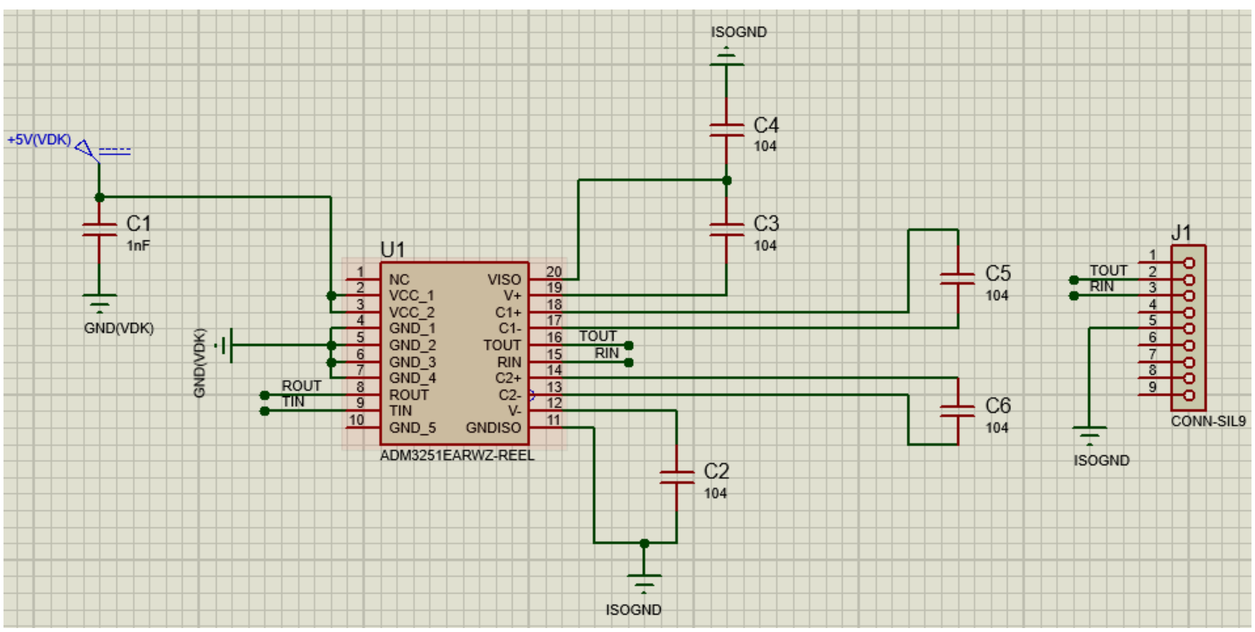
3.7. **The media.**

a. Design Request:

- Communicate RS232 , RS485
- Isolation with microcontroller
- High accuracy and reliability

b. Method: Use IC ADM3251E

- **RS232**

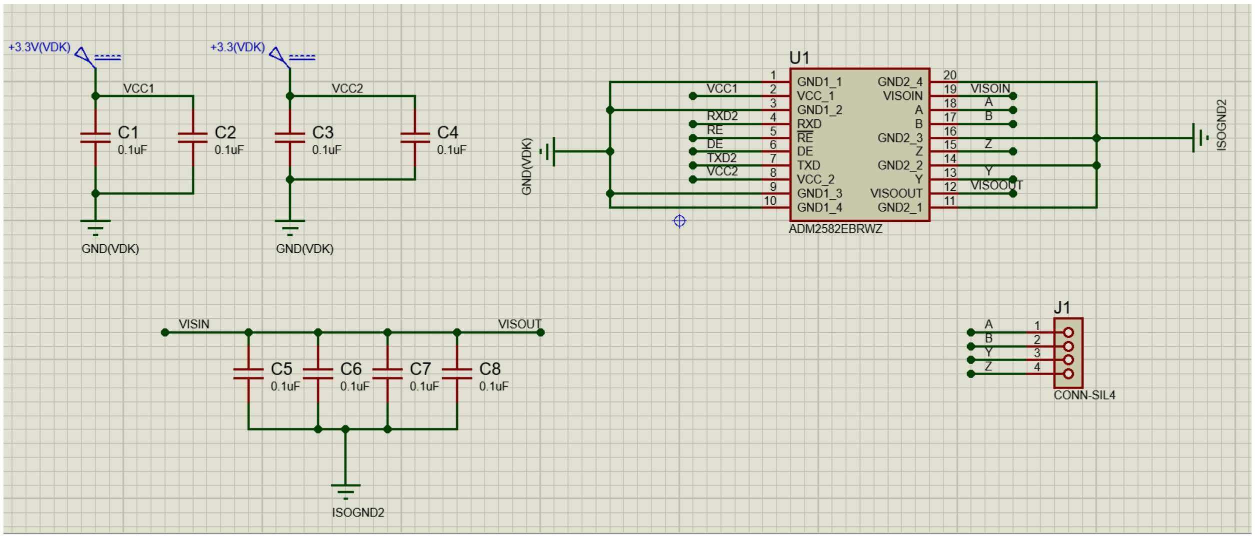


Use IC ADM3251E of Analog devices has:

- Isolate single channel RS 232
- 460 kbps data rate

- 1Tx and 1Rx
- ESD protection on R_{in} and T_{out} pins.
- Intergrated isolated DC to DC converter
- Working voltage : 5V or 3.3V
- Working temperature : $-40°C\ to + 85°C$

- **RS485**



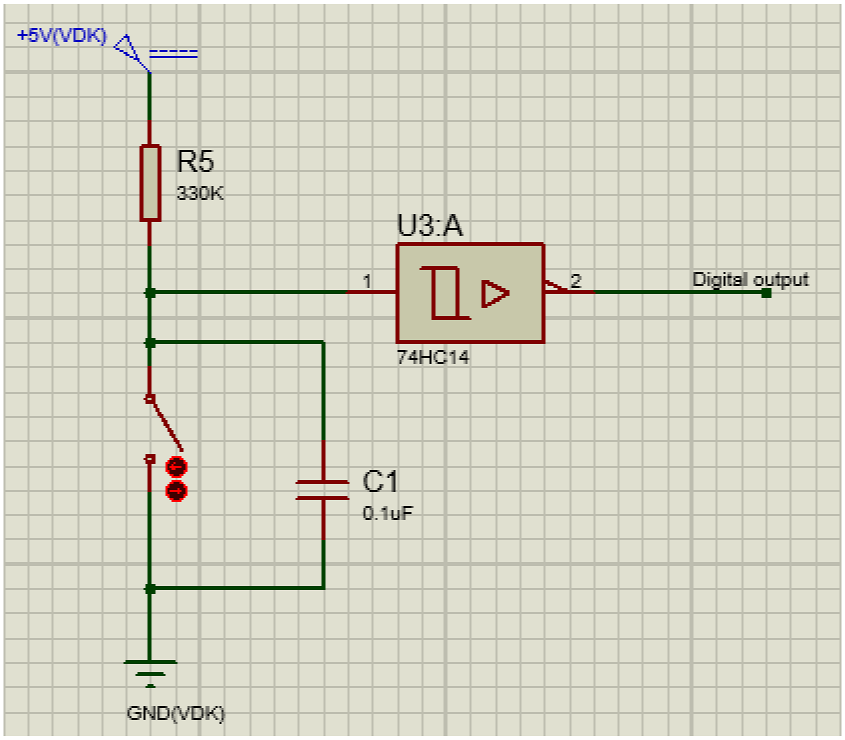
Use IC ADM2582E of Analog devices has:

- Isolated RS485 transcelver
- Configurable as half or full duplex
- Integrates isolated DC to DC converter
- ADM2582E data rate: 16Mbps
- 5V or 3.3V operation
- Connect up to 256 nodes on one bus
- Operating temperature range : $-40°C\ to + 85°C$

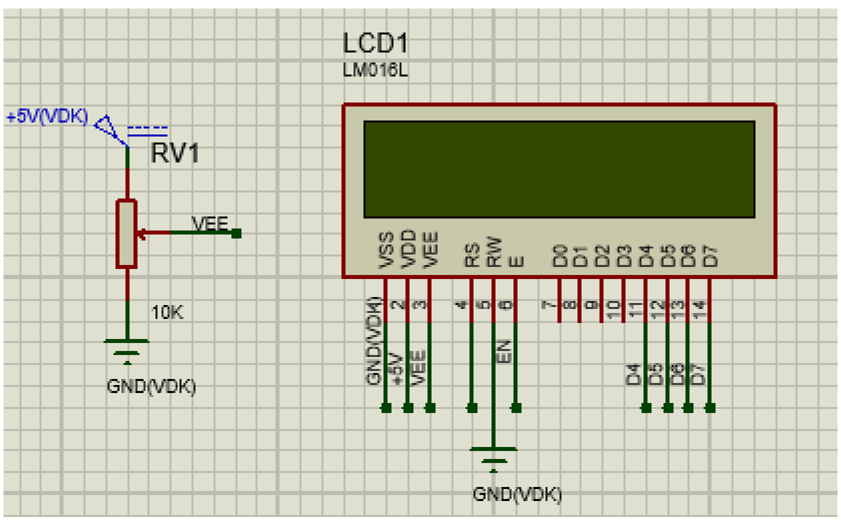
3.8. Button and LCD

- **Button**

Designed to prevent key vibration: using capacitor C89 and IC 74HC14



- **LCD: Use LCD 16x2**



3.9. Power supply

a. Design Request:

There are two sources isolated from each other :

+ Power 1: Supply voltage for microcontroller, LCD, button

+ Power 2: Supply voltage for other components.

b. Method :

+ Use source module 24VDC-20A in industry.

+ Use Buck-Converter to reduce voltage to voltage levels: 15VDC, 8VDC.

+ Then use linear sources to generate voltage 12VDC,5VDC provided OPAM , ADC,...

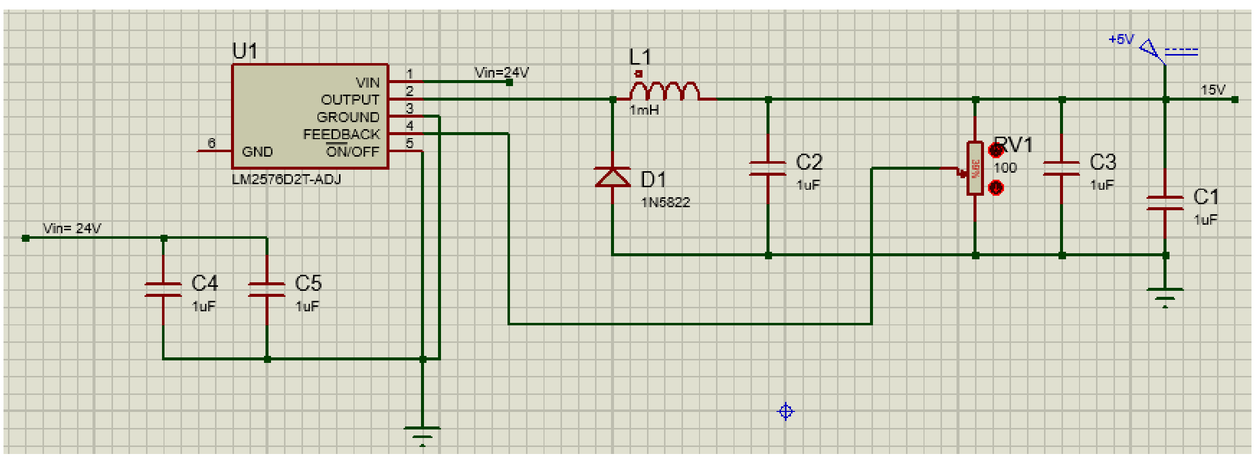
+ Use an isolating power IC to create an isolated source.

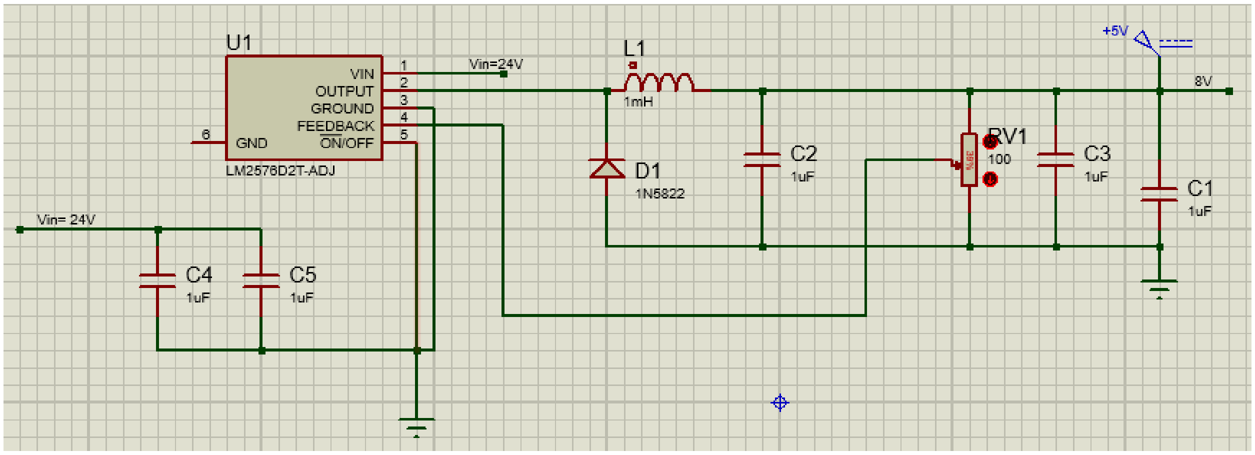
- **Use IC LM2576ADJ Buck step down to reduce voltage**
  - Guaranteed 3.0 A output current
  - Wide input voltage range: 8V-40V
  - Output voltage range: 1.23V – 37V

Change the rheostat to achieve the desired voltage**.**

Components are selected according to the datasheet of the LM2576.

When installing the circuit, we adjust the resistors R1 and R2, of the pulse source to achieve the desired voltage would like.

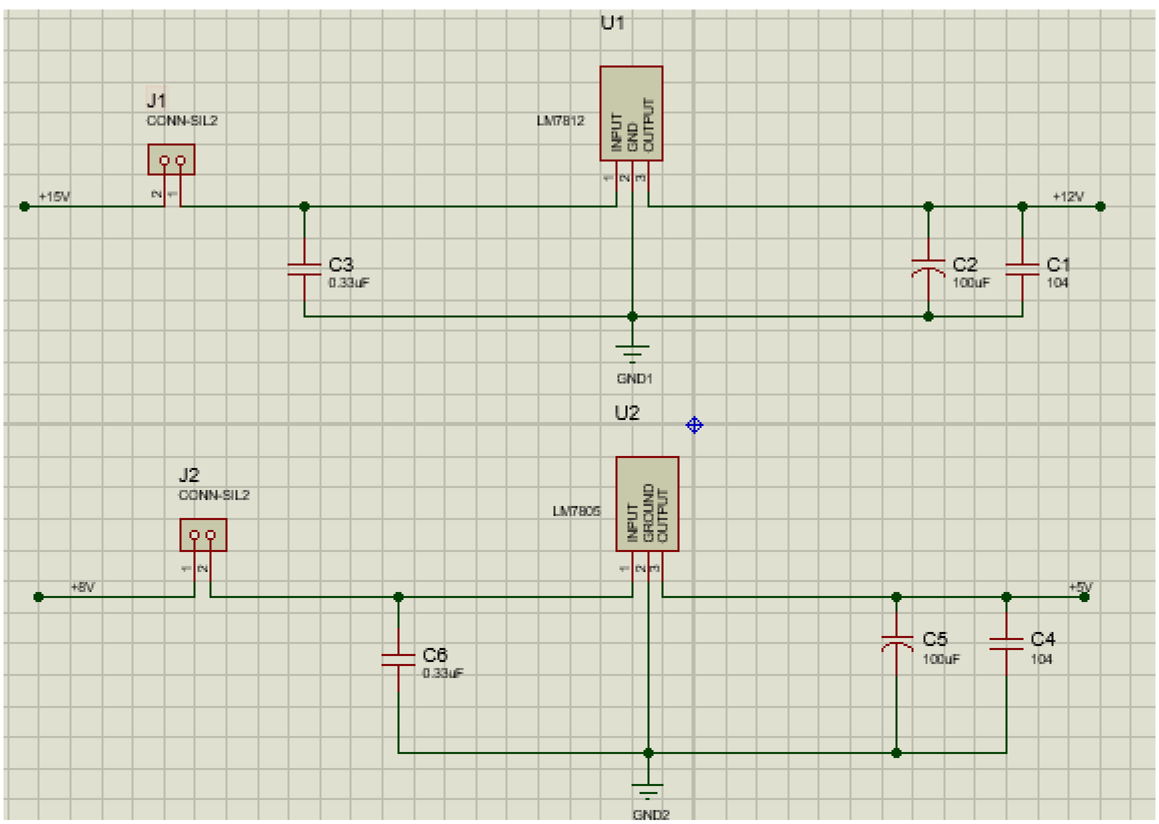




- **Linear source:**

Use IC LM7805, LM7812: Components are selected according to the datasheet of the LM7805,LM7812.

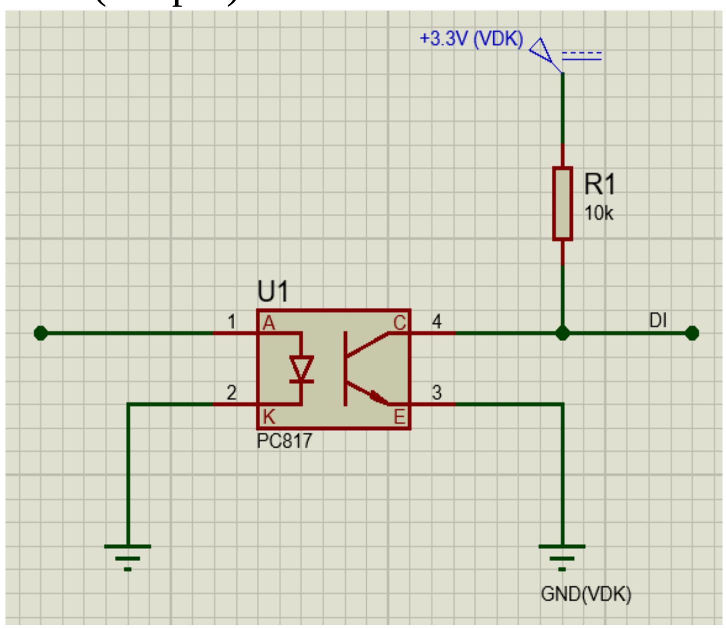
Use Jump at J1, J2 . This helps to avoid putting too high a voltage on the source linear because the resistance has not been adjusted when the circuit is first installed.



- **Isolating power IC**

Calculate the total power of the components using the same source isolated with the Microcontroller (including 3.3V and 5V). Only calculate the power on the part shared with the Microcontroller:

- Microcontroller STM32F103C8T6: Maximum current consumption: 300mA (3,3V) ⇔0.3*3.3=0.99W
- LCD: 15mA(5V)⇔75mW=0.075W
- Total button and led: 30mA(3.3V)⇔0,099W
- Digital input isolation (4 input):



The maximum current flowing through the C terminal of PC 817:

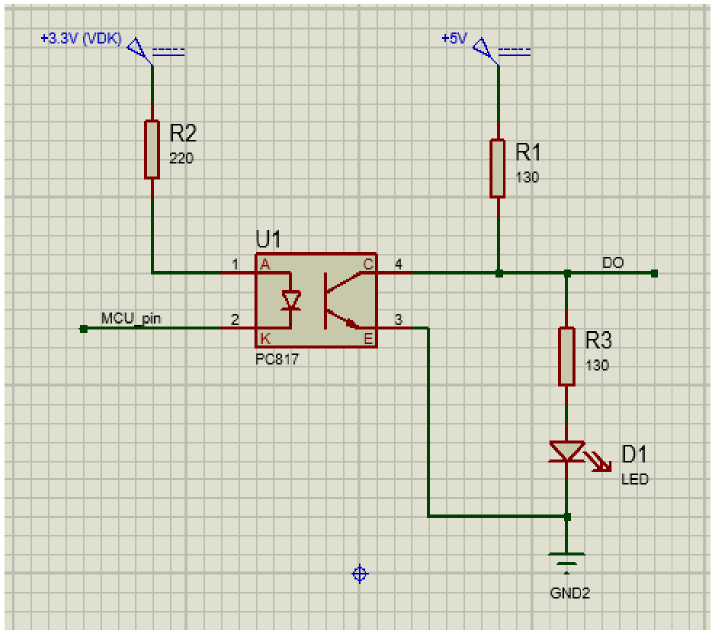
$$I_C = \frac{3.3}{10000} = 0.33A$$

Because Uce saturation is very small, it is considered that PC817 does not consume 3.3V power source in common with the Microcontroller.

⇨ Max power of R1: $(0.33.10^{-3})^2.10000 = 0.001089W$

⇨ Total power of 4 components = $0.001089 \times 4 = 0{,}004356W$

- Use DO circuit (4 DO):



+ when PC817 block.

As calculated in the DO part, the current flowing through the IR Led is from 6-10 mA, the voltage drops from 1.2-1.4V, so we will choose the value of 10mA and 1.4V to calculate the power.

Power of R_2: $(10.10^{-3})^2.220 = 0.022W$

Power consumption of IR LED: $1.4 * 10.10^{-3} = 0.14W$

⇨ Total power consumption of 4 DO: (0.14+0.022)*4=0,648W

- IC ADUM4154

Parameter	Symbol	Min	Typ	Max	Unit	Test Conditions/Comments
SUPPLY CURRENT						
A Grade and B Grade	I_{DD1}		4.8	8.5	mA	C_L = 0 pF, DR_{FAST} = 1 MHz, DR_{SLOW} = 0 MHz
	I_{DD2}		6.5	13	mA	C_L = 0 pF, DR_{FAST} = 1 MHz, DR_{SLOW} = 0 MHz

With speed 1MHz, maximum current flowing to the pin I_{DD1} is $8.5mA$

⇨ Power ADUM4151 with 5V source: $5*8.5*10^{-3} = 0.0425W$

- IC ADM3251.

DC-to-DC Converter Enabled				
Input Supply Current, $I_{CC(ENABLE)}$		110	mA	V_{CC} = 5.5 V, no load
		145	mA	V_{CC} = 5.5 V, R_L = 3 kΩ
V_{ISO} Output[2]	5.0		V	I_{ISO} = 0 µA

Maximum current flowing ADM3251 from 5V source is 145mA

⇨ Power ADM3251: $5*145*10^{-3} = 0.7W$

- IC ADM2582 :

ADM2587E SUPPLY CURRENT	I_{CC}				
Data Rate ≤ 500 kbps			90	mA	V_{CC} = 3.3 V, 100 Ω load between Y and Z
			72	mA	V_{CC} = 5 V, 100 Ω load between Y and Z
			125	mA	V_{CC} = 3.3 V, 54 Ω load between Y and Z
			98	mA	V_{CC} = 5 V, 54 Ω load between Y and Z
			120	mA	120 Ω load between Y and Z

Power consumption of ADM2582 with 3.3V source:

$3.3*125*10^{-3} = 0,412W$ and $3.3*90*10^{-3} = 0.297\ W$

The total power consumption of components using isolated 5VDC and 3VDC sources is:

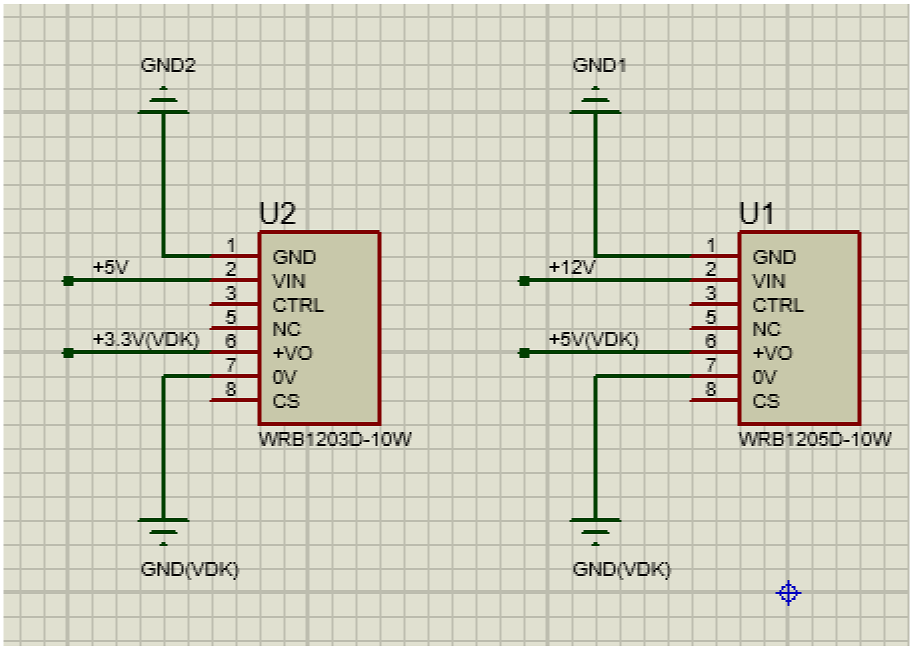
P = 0.99 + 0.075 + 0.099 + 0.004356 + 0.648 + 0.0425 + 0.7 + 0.412 + 0.297 = 3.267856

⇨ Select the Mornsun WRB-1205D-10W isolating source IC with the following parameters:

- Input voltage range: 9-18 VDC
- Output voltage 5V, maximum output current 2A.
- Efficiency 80%.

⇨ Select the Mornsun WRB-1203D-10W isolating source IC with the following parameters:

  - Input voltage range: 9-18 VDC
  - Output voltage 3.3V, maximum output current 3.03A.
  - Efficiency 77%.



3.10. Microcontroller

From the hardware requirements and design diagram mentioned above, the minimum Microcontroller needed is 28 pins in and out, including:

+ Button

+ Pin UART(2 UART)

+ Pin connect LCD

+ 2 pin PWM

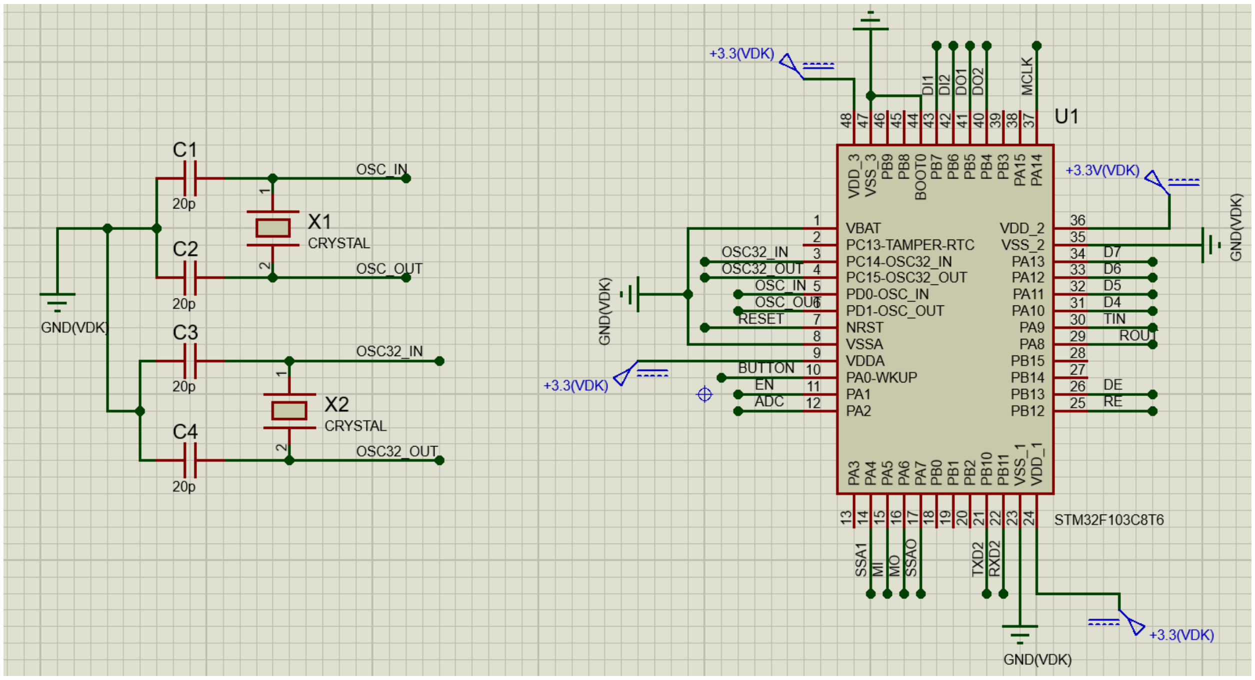
+ 4 pin DI

+ 4 pin DO

+ 1 pin ADC loop current

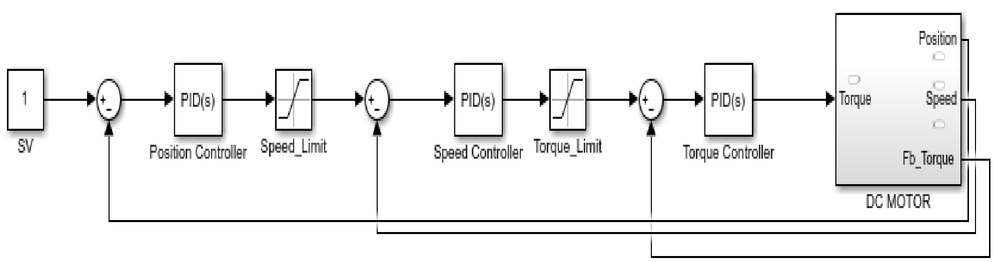
+ 5 pin connect SPI with IC isolated

⇨ Choose microcontroller STM32F103C8T6



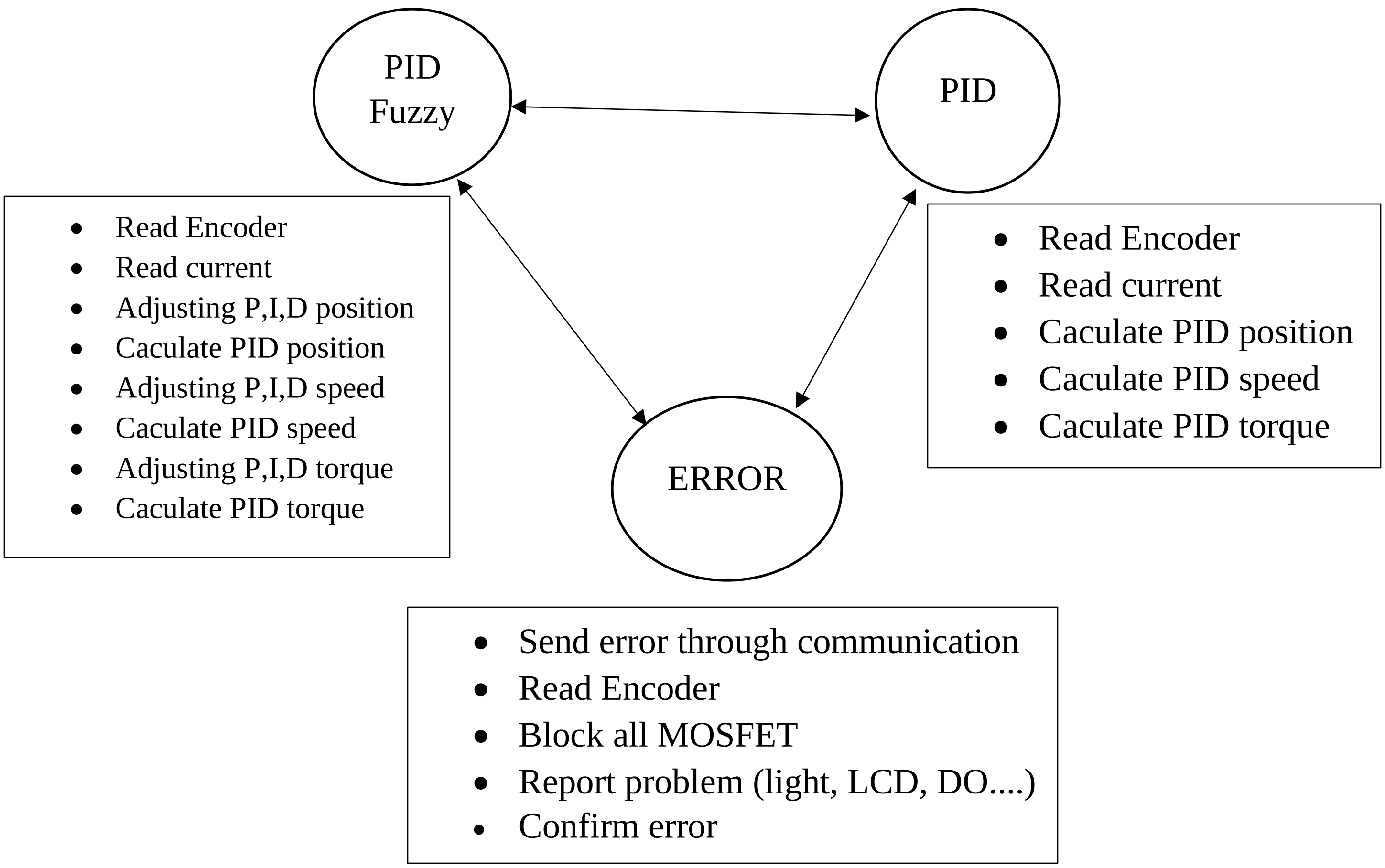
IV. Design software

4.1. Control Algorithm



The controller has 3 control loops: Torque loop, speed loop, position loop.

4.2. **State diagram of the control process**



- The control program is placed in the timer 1 interrupt (reads the encoder and calculates the control signal) and timer 2 (read current value).
- Torque loop sampling time: 50us
- Speed and position loop sampling time: 100us
- Description the state diagram of the control process :

The control process is defined with 3 states: Intelligent control (Fuzzy PID), PID dictionary and error status:

- Intelligent control (Fuzzy PID): The system will read the values from the current meter circuit and the encoder calculates the errors and the difference derivative. From there, adjust the parameters of the sets current PID control to get the right control signal.
- PID dictionary : The parameters of the PID controller for position, speed and torque are all set by the consumer. The task of the system is to calculate the control signals based on the above fixed parameters.
- Error status: This state appears when the system shows an error signal, the system will immediately send the error through communication, notify the user of the problem via lights, buzzer, LCD, while it is necessary to lock all Mosfet. When there is no error signal as well as acceptance signal from the other two states, the system will return to one of the above two states for normal operation (relying on the variable S1 to save the operating state before jumping into the error state).
- **Functions to use**

read_encoder():is used to read the value from the encoder which to calculate the value of the actual position and speed.

read_current() : used to read the actual current value.

U1 **= PID_vitri(**sv_vitri, vitri, P1,I1,D1**):** is used to calculate the control signal of the PID location (if you choose the location). Input parameters include: sv_vitri (set value), vitri (actual value) and P1, I1, D1 are the parameters of the position PID controller.

sv_tocdo **= PID_vitri_limit(**0, U1, max_vitri**):** Takes one input as output of PID_vitri U1, the limit of control signal of position PID controller is theoretically calculated. The remaining inputs include the min value (0) and the max value of the control signal. The output of this function will be an input to the speed PID**.**

U2 **= PID_tocdo(**sv_tocdo, tocdo, P2, I2, D2**):** used to calculate the control signal of the speed PID unit. The input parameters include: sv_tocdo (set value), tocdo (actual value) and P2, I2, D2 are the parameters of the position PID controller.

Sv_torque **= PID_tocdo_limit(**0, U2, max_tocdo**):** Take an input as output of PID_tocdo U2, limit the control signal of the position PID controller to be theoretically calculated. The remaining inputs include the min value (0) and the max value of the control signal. The output of this function will be an input to the moment PID.

U3 = PID_moment(sv_moment, moment, P3,I3,D3): used to calculate the control signal of the PID moment. The input parameters include: sv_dongdien (set value), dongdien (price actual value) and P3, I3, D3 are the parameters of the position PID controller.

Duty = PID_dongdien_limit(0, U3, max_dongdien): Take an input as output of PID moment U3, limit the control signal of position PID controller is calculated theoretically. The remaining inputs include the min value (0) and the max value of the control signal. The output of this function will be the duty cycle to adjust the mosfets.

fuzzy_vitri(P1, I1, D1, e_vitri, e_vitri_dot): Setting the parameters of the position PID.

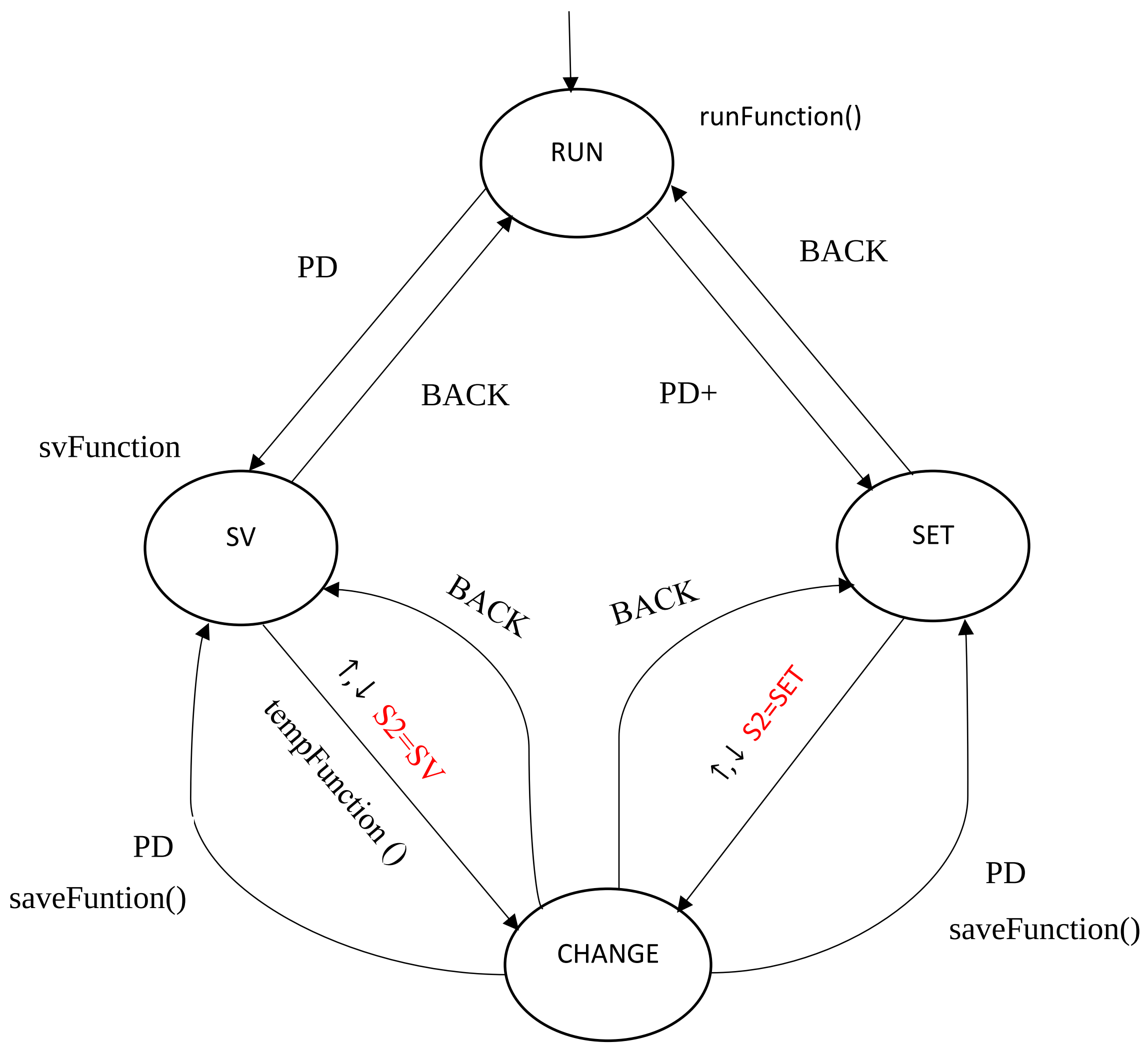
fuzzy_tocdo(P2, I2, D2, e_tocdo, e_tocdo_dot): Adjust the parameters of the speed PID unit.

fuzzy_moment(P3, I3, D3, e_dongdien, e_dongdien_dot): Set the parameters of the PID moment.

set_duty(Duty): Adjust the mosfets of the H-bridge according to the given Duty value pre-calculated.

error_state():execute when error signal = 1, close mosfets with set_duty(0) command, send error message through communication and turn on LED or LCD to notify user. Wait until error signal = 0, then return to the previous working state.

4.3. State diagram of interface



- **Description** :

The program interface is placed in the While(1) loop.

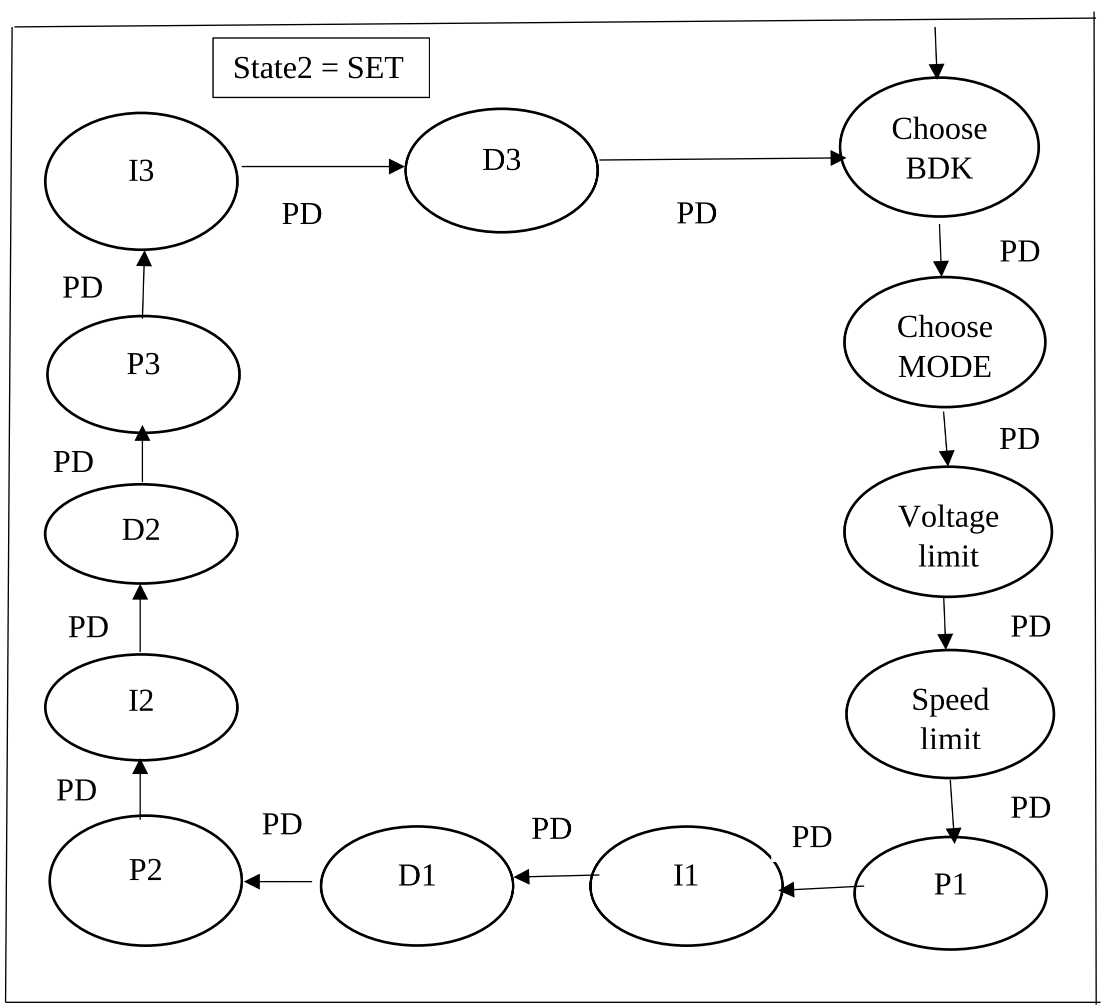
Have 4 state:

- **Run state** : Is the first state when executing the program. This state executes the commandrunFunction to display the set and actual values of the joystick quantity. When the button is pressed

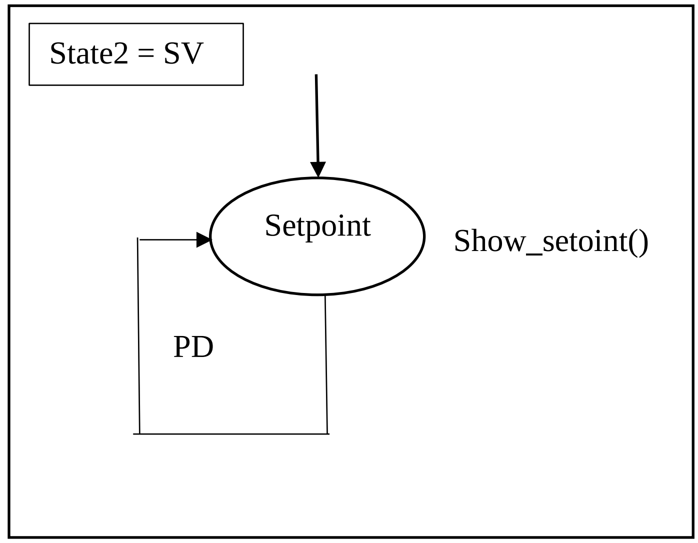
PD, this state will change to SV (set value), and when PD+ will change to SET state.

- **SET state** : Status's mission SET state is to display the parameters of user-replaceable controller change. Every time the PD key is pressed, the system will in turn display: BDK (position, speed), MODE (intelligent control or traditional PID control), voltage limiting and speed limit, position P, I, D parameters position, speed and torque. If the user want to change a certain parameter (increase or decrease) the user will press the ↓/↑ key. At this point, the system will switch to state CHANGE. When you want to get out of the situation SETTING state, the user presses the . key BACK to return to RUN state.

Note: to solve the following problems hey, we create a variable state2 to distinguish the state state between SET and SV. In this state, state2 = SET.

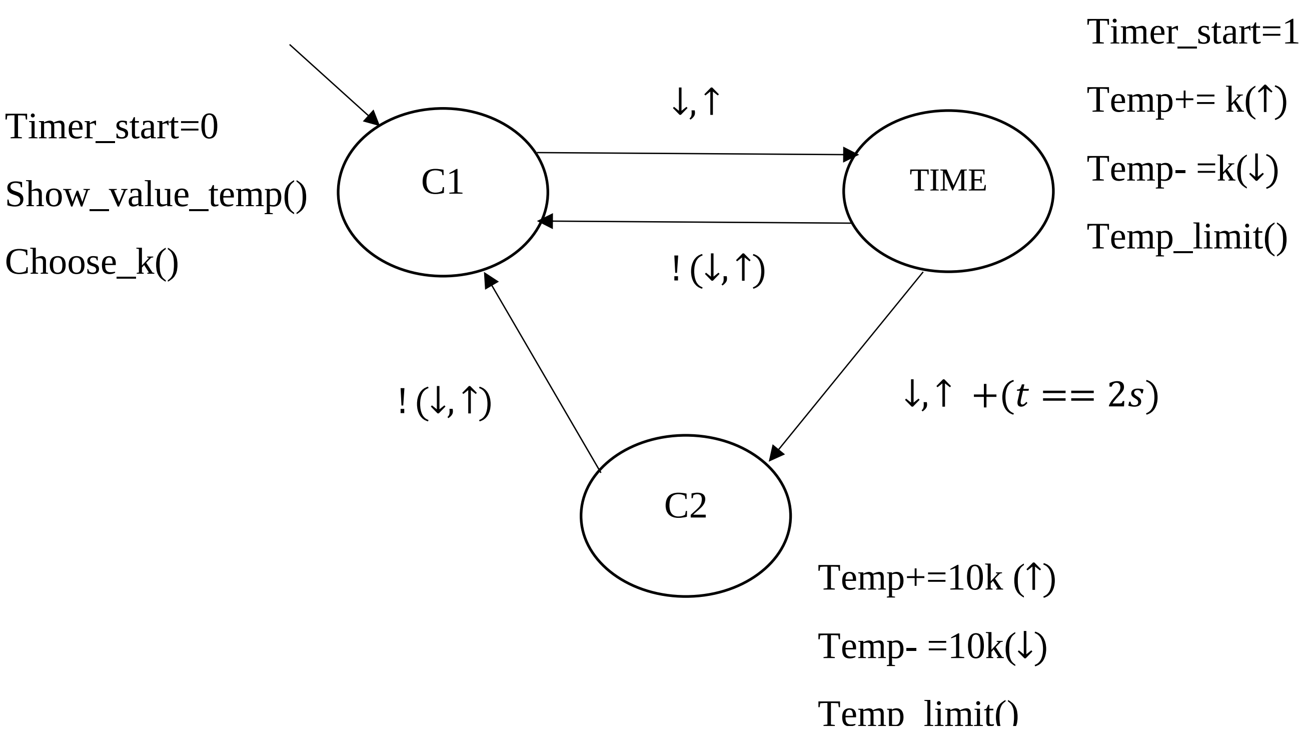


- **SV state:**



SV state has the task of displaying the price the set value of the quantity we want to control (position, speed, degree). Similar to the SET state, if the user who wants to change the set value (increase or decrease) will press ↓/↑ key. At this point, the system will switch to state CHANGE. When you want to get out of the SV state, you press the BACK key to return to the RUN state.

- **CHANGE state**:



The CHANGE state has a function to help the user change the parameters displayed in the SV and SET states, appear when the user presses the ↓/↑ key while in 2 states this. Two variables temp1, temp2 are created to store the quantity name to be changed (setpoint, vitri, tocdo, P1, I1, D1, …) and the current value in SV or SETTING. This state consists of 3 states lower level:

- **C1**: In this state, the system displays the quantity that the user wants to change automatically calculate the change step k every time ↓/↑ key is pressed. Here I convention: Parameters: P1, P2, D1, D2, then k=0.1; Parameters: V_limit, N_limit, I1, I2, SV (speed BDK), BDK, MODE then k=1; SV when selecting position BDK, k=0.01. When the user wants to change any quantity, press ↓/↑ to switch to Time state.
- **Time**: As soon as we enter this state we start a timer function Timer_start = 1, each time a key ↓/↑ is pressed, the variable temp2 will increase by k.This state also has the function of limiting a maximum value that the user can change. If no ↓ /↑ key is pressed, the system returns to state C1, reset timer. Conversely, when the user presses the ↓/↑ key for more than 2s (determined by the timer), the system will go to state C2.
- **C2**: When in the C2 state, depending on this time the user has pressed ↓/↑ for more than 2s, but the temp2 will increase or decrease by an amount of 10k. This state also has the function of limiting one pole value user-modifiable format like C2. When the ↓/↑ key is no longer held down, the The system switches back to state C1.

From the CHANGE state, if you want to save the changed values, the user presses the PD key, thanks to the previously assigned state2 variable, the system will know to return to the SV or SET state. If we don't want to save the changed values, press BACK key. Also thanks to the state2 variable, the system knows which state to return to.

- **Function to use:**

runFunction(): displays the set value and actual value as well as the name (vi tri, toc do) of the quantity to be controlled. At the same time, there is a loop that waits for the PD + or PD key combination to assign state2 corresponding to the state SETTING or SV.

svFunction(): Displays the name and set value of the control quantity

settingFunction(): Initialize a variable state3 to store the internal child states, display the values in the controller's setting panel through the PD key in turn, waiting for the ↓/↑ key from the user to jump to other states thanks to the state2 variable.

tempFunction():while in SV or SETTING state and a key is pressed, call this command.

Here I convention: Parameters: P1, P2, D1, D2, then k=0.1; Parameters: V_limit, N_limit, I1, I2, SV (speed BDK), BDK, MODE k=1; SV when selecting position BDK, k=0.01. This command has the function ability to create two variables temp1 and temp2, temp1 to store the name of the quantity to be controlled, temp2 to store present value for that quantity.

changeFunction(temp1, temp2): create a variable state4 to store the child states, define the state current state4 is C1, C2 or Time and increase and decrease temp2 as explained above. In the changeFunction command invokes commands such as lua_chon_k(), hien_thi_temp(), and temp_limit().

- **k = lua_chon_k(temp1):** This command is based on temp1 to give the corresponding k value HereI convention: Parameters: P1, P2, D1, D2, then k=0.1; The parameters: V_limit, N_limit, I1, I2, SV (speed BDK), BDK, CHEDO k=1; SV when selecting position BDK, k=0.01.
- **hien_thi_temp():**Display two variables temp1 and temp2 on LCD

- **temp_limit(temp1, temp2)**: This instruction relies on temp1 to determine the maximum value of temp2 what is it, if temp2 has reached its maximum then pressing /↑ won't change it variable value temp2

saveFunction(temp1, temp2): save the adjusted temp2 value in the CHANGE state to the corresponding quantity in SV or SET.