Implementing An Analog Approach For Closed Environment Autonomous Temperature Control Circuitry

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***Abstract*—*İşte konforlu bi çalışma ortamı için ofislerde evlere, her yerde bulunduğumuz iklimi kontrol altında tutmalıyı uygun olmayan sıcaklık ve neme sahip ortamlar çalışma per formansını düşürebilir ve konforu azaltabilir. Bu sebeple klim kopntrol üniteleri falan elzem. Bu işlemi dijital circuitlar il kolay bir şekilde yapabiliriz fakat analog circuitlar ile yapmakta daha maliyetli olabilir. Biz bu projede tamamen analog temeller dayanan ve aldığı sıcaklık ölçümlerine göre ısıtıcıyı veya fan çalıştırarak sıcakığı belli bir aralıkta tutan bir proje üzerin çalıştık.**

***Index Terms*—**

I. Introduction

Whether it is an office, home or a restaurant the climat should kept under control for establishing comfort. Air conditioners provide this with heating, cooling or humidifying operations. Most of the air conditioners are digital hence have some limittions. Designing a digital air conditioner is

II. Problem Definition

In this project, design and implementation of a micro air conditioner will be discussed. The function of the conditioner is either heating and cooling. It compares the ambient temperature with the desired temperature. If the ambient temperature is less than the desired temperature, it operates the heating mode. Otherwise it operates the cooling mode. The project consists of four units; namely, sensing, control and operation and display units. The sensing unit perceives the ambient temperature and sends this information to the control unit. Also, there is another designed a simple circuit to take the information of desired temperature. This unit also sends its output to the control unit. Control unit compares the two temperatures and decides the action to be taken by the operation unit. Operation unit is where the heating and cooling systems are. It operates one of these systems according to the signal sent from the control unit. Display unit shows the ambient and set temperature by mapping them into a color spectrum. The block diagram of the project can be seen in Figure 1.

For each of these units we had some design specifications. Details of how we achieved these specification will be given in the related section, however we provide those specifications here for the sake of completeness.

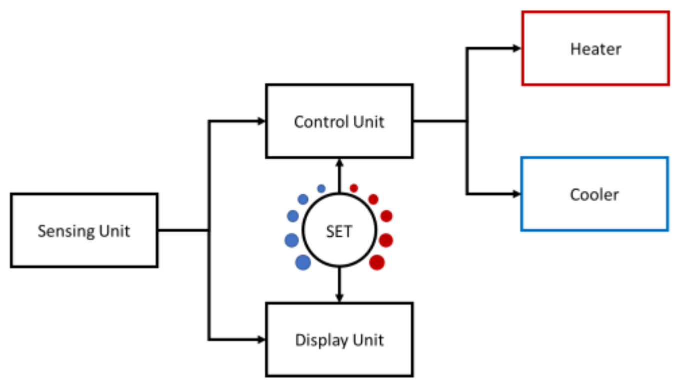


Fig. 1. Block diagram of the micro air conditioner

- abc

III. Unit Operations

In this section, first, proposed way of designing the units are explained. Then, simulation and experimental results are shared. Finally, findings are discussed. For the simulations, LTspice is used and its results are plotted using MATLAB. In the circuits, the DC supply's $\pm 25V$ terminals are arranged to provide $\pm 12V$ and used along with the GND connection to drive the circuits.

A. Sensing Unit

Sensing unit converts the ambient temperature into a DC voltage signal which the control unit can process. Output of this unit is $0V$ and $9V$ voltage for the $24°C$ and $40°C$ temperatures, respectively. Between these temperature levels, it has a linear increase in the output voltage. Outside of this temperature range, it performs clipping in the voltage levels. First discussion on the sensing unit was to select a temperature sensor. With the price and linearity properties considered, LM35 was decided to use.LM35 has three terminals corresponding to supply voltage, ground, and output voltage. By supplying it with $4V$ to $20V$, its output terminals relation with the ambient temperature is given in the Equation 1 [1]

$$V_{out} = 0mV + 10\frac{mV}{°C} \tag{1}$$

$12V$ and ground terminals of the power supply is connected to LM35. Using the output of LM35, four specifications mentioned above had to be attained. First, to have $0V$ when the ambient temperature is $24°C$ offset voltage of $10mV/°C * 24°C = 240mV$ had to be eliminated. Then, since LM35 gives an increase of $10mV/°C*(40-24)°C = 160mV$ between the temperature range, the signal should be amplified $\frac{9V}{160mV} \approx 56$ times. To obtain the offset voltage value, the voltage divider circuit in Figure 2 is used. Here, the Zener diode is used as a voltage regulator to avoid possible oscillations of the voltage source. The voltage on the Zener diode is divided using resistors, and the voltage on the one of the resistors are taken. In the following parts, a diode is used in the circuit. Hence, to eliminate its voltage drop either, the resistance values are arrange to give the sum of $240mV + 700mV = 940mV$ as the voltage output. Then, this voltage is fed to a voltage buffer to isolate it from the rest of the circuit.

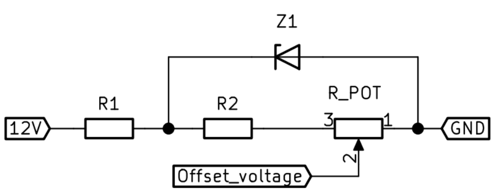


Fig. 2. Offset voltage to be subtracted

$$V_{Amplified\_signal} = \frac{R_4}{R_3} \cdot (V_{LM\_35} - V_{Offset\_voltage}) \tag{2}$$

$$0 \leq Cpot \leq 1 \ and \ \frac{12 \cdot (R_{POT} + R_2)}{(R_{POT} + R_2) + R_1} \leq V_{Z_1} \tag{3}$$

$$V_{Offset\_voltage} = V_{Z_1} \cdot \frac{R_{POT} \cdot C_{POT}}{R_2 + R_{POT}} \tag{4}$$

Afterwards, a difference amplifier using an opamp in Figure **??** is used. This circuit meets the need of both subtracting the offset voltage from the LM35 reading and amplifying it 56 times. The analysis of this configuration is provided in Appendix **??**

$$V_{Amplified\_signal} = \frac{R_4}{R_3} \cdot (V_{LM\_35} - V_{Offset\_voltage}) \tag{5}$$

Then, to achieve clipping, two components are used. A diode to eliminate negative voltages and a $9V$ Zener diode in clipping configuration to limit the voltage level to $9V$. The configuration can be seen in Figure 15. When the temperature

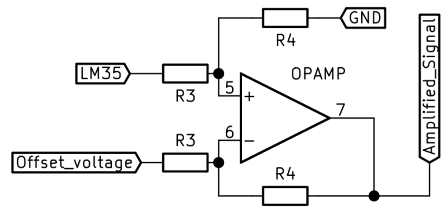


Fig. 3. Difference amplifier with a gain of R4/R3

level is below the $24°C$, the amplified signal obtained from the difference amplifier is negative. Then, the diode does not allow any current flow on it resulting in $0V$ in its other end. When it is larger than 9 V, the Zener diode clips the voltage across is to $9V$. The ratio of the resistance values are taken to be high in order to not lose the amplified signals value on the resistor series to it much.

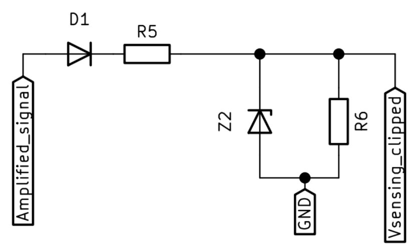


Fig. 4. Clipping circuit

$$V_{sensing\_clipped} = (V_{Amplified\_signal} - V_{D_1\_ON}) \cdot (\frac{R_6}{R_5 + R_6}) \tag{6}$$

Consider $R_5 << R_6$ and $V_{Amplified\_signal} = V_{AS}$;

$$V_{sensing\_clipped} = \begin{cases} 0V & \text{if } V_{AS} < V_{D1\_ON} \\ V_{Z2} & \text{if } V_{AS} - V_{D1\_ON} > V_{Z2} \\ V_{AS} - V_{D1\_ON} & \text{if } Otherwise \end{cases} \tag{7}$$

Then, this voltage is again fed to a voltage buffer, and the output of the buffer is the overall output of this unit which is denoted as $V_{sensing}$. The change in the output voltage with respect to the ambient temperature is given in equation 8

$$V_{sensing} = 0.56(C_{ambient} - 24)V \tag{8}$$

Apart from the function of the system, some LED lights are added to the circuit to verify the correct operation. To observe the output voltage level without affecting the circuit in Figure **??** is used where the current through the LED is controlled by the output voltage level. This allows to check the output voltage level by observing the LED lights intensity.

$$V_{sensing} = V_{sensing\_clipped} \tag{9}$$

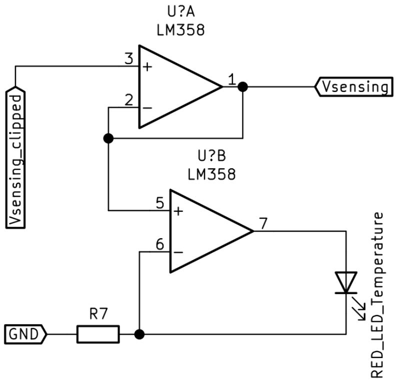


Fig. 5. Buffering $V_{sensing\_clipped}$, and $V_{sensing}$ magnitude indicating

$$I_{RED\_LED\_Temperature} = \frac{V_{sensing}}{R_7} \tag{10}$$

So by combining equations xxxxxxx

$$V_{sensing} = \frac{R_4}{R_3} \cdot (V_{LM\_35} - V_{Offset\_voltage}) \tag{11}$$

Also, the DC power supply terminals are connected to LED lights through resistors to verify the proper connection of those terminals. Configuration of this part can be seen in Figure **??**.

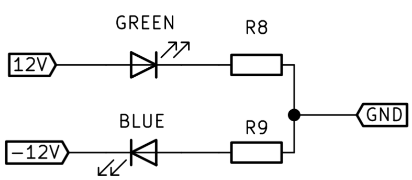
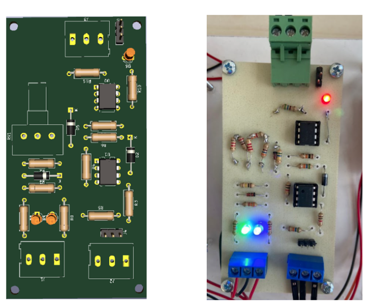


Fig. 6. +12V, GND and -12V indicator LEDs



(a) (b)

Fig. 7. Designed (a) & assembled (b) PCBs of the sensing unit.

B. Set Unit

Set unit is where the user specifies the desired temperature. This unit is responsible of converting the desired temperature level into a voltage signal which to be compared with the sensing units output. To achieve this, a basic circuit with a potentiometer is utilized. User can control the knob of the potentiometer until the desired temperature level's color is observed at the display unit. Since the sensing unit gives output between the 0 and $9V$, same voltage range should be available in the set unit either. To achieve this, the circuit in the Figure 8 is designed. The output voltage level is taken from the middle leg of the potentiometer. This assures a linear increase in the voltage level when the knob is turned. Ideally, $0V$ output voltage is wished when the potentiometer gives 0Ω between its middle and lower legs. Hence the R? resistance should be chosen 0. But, to compensate for possible unidealities in the sensing units output voltage, minimum output voltage of this unit is chosen to be $0.25V$. Similarly, maximum output voltage is chosen to be $8.75V$. Hence the resistance values are chosen accordingly. The opamp is used as a buffer for isolation purposes. Similar to the sensing unit, the relation between the output of this unit and the set temperature is given in the equation 12.

$$V_{set} = 0.56(C_{set} - 24)V \tag{12}$$

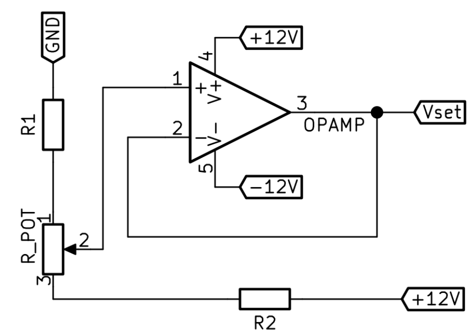


Fig. 8. Schematic of the set unit

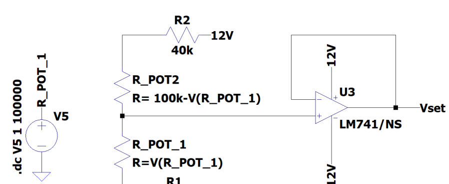


Fig. 9. LTspice model of the set unit

C. Control Unit

Control unit is where the signals from the set and sensing units are compared and the corresponding action ,heating or cooling, is determined. This unit takes two inputs $V_{sensing}$ and V_{set} and produces two outputs $V_{heating}$ and $V_{cooling}$. The desired relation between these signals are given in the Table II where V_{rest} and $V_{operate}$ are chosen to be 0 and $12V$ respectively.

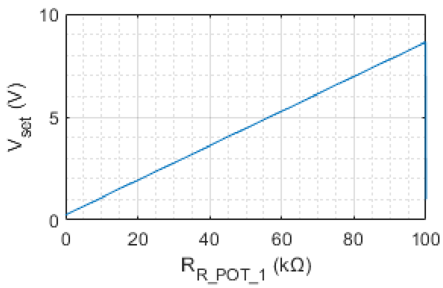


Fig. 10. LTspice simulation results of the set unit

TABLE I
INPUT OUTPUT RELATIONS OF THE CONTROL UNIT

$V_{sensing} - V_{set}$	> 0	< 0	$= 0$
V_{heater}	V_{rest}	$V_{operate}$	V_{rest}
V_{cooler}	$V_{operate}$	V_{rest}	V_{rest}

First step of this unit is taking the difference of the V_{set} and $V_{sensing}$. A difference amplifier in Figure **??** can be used for this action. While making the subtraction, the resistance values are chosen to give a gain of 18.8. Using this gain and 8 and 12, the relation between $V_{set} - V_{sensing}$ and the temperature difference between the ambient and set temperature reduces to the equation 13 which means each $10V$ in the output voltage of the difference amplifier corresponds to $1°C$ difference between the ambient and set temperatures which is easy to work with.

$$V_{set} - V_{sensing} = 10(C_{set} - C_{sensing})V \tag{13}$$

To obtain the relation in table II from the output of the difference amplifier, a comparator should be utilized. But using a basic comparator can make the system vulnerable for oscillations between heating and cooling operations. Hence, schmitt trigger topology is chosen to apply. Schmitt trigger is a circuit topology that can be implemented with an opamp which has the v_{in} vs v_{out} characteristics in Figure 11.

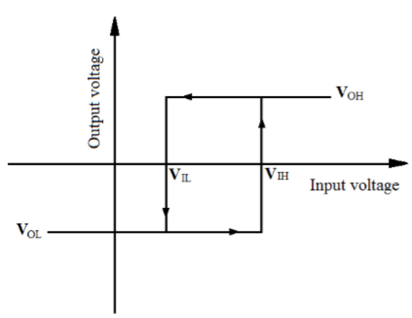


Fig. 11. Schmitt trigger

A normal comparator characteristics has a change in the output voltage at just one point which makes it unstable around that input voltage value. This characteristics does not have that problem since it requires V_{IH} amount of input voltage to have V_{OH} amount of output voltage but the output voltage does not change unit the input voltage is reduced to V_{IL}. Circuit implementation of the schmitt trigger is given in Figure **??**

Here, by substituting the output voltage of the difference amplifier as the input value, the resistance values can be chosen such that the output voltage???? Here, V_{ref} is ??. Desired V_ref can be obtained from the circuit in Figure **??**. This circuit is very similar to the one used at the sensing unit to obtain the offset voltage in Figure 2. There is a zener diode to suppress the oscillations in the power supply and a voltage divider circuit between its tips. The resistance values are chosen to give $??V$ as the reference voltage.

As a last step, circuit in Figure **??** is used. The output of the schmitt trigger is passed through a diode and connected to the ground through a resistor to make the negative voltages 0. Also, the output from the diode is connected to a red led to indicate the operation element is working. As can be seen from the Figure **??**, voltage at the tip of the diode is the overall output.

Note that there are two circuits in this unit. Output of one of which is producing $V_{heating}$ and the other one is producing $V_{cooling}$. The diagram of both of these circuits are the same and explained above except for the subtraction direction in the difference amplifier. For $V_{heating}$, $V_{sensing}$ is subtracted from the V_{set} as explained above. For $V_{cooling}$, V_{set} is subtracted from the $V_{sensing}$.

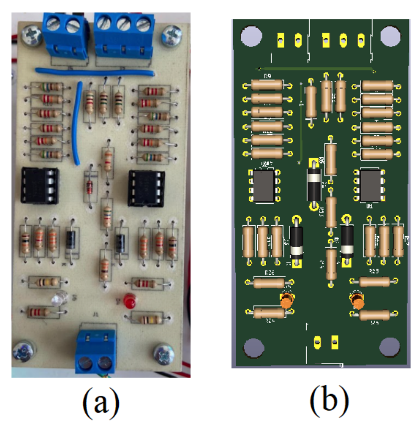


Fig. 12. Designed (a) & assembled (b) PCBs of the control unit.

D. Operation Unit: Heating and Cooling

Operation unit is isolating the power circuitry from the rest of the design. It is responsible for conducting the specified operation by the control unit. This unit has two input terminals corresponding to the output terminals of the control unit for heating and cooling operation.As explained in the related section, control unit sends $V_{operate} = 5V$ for the operation it wants to take place and $V_{rest} = 0V$ for the one it does not. Hence, this unit should act like a switch for the heating and cooling elements which is on when the input is $5V$ and off when it is $0V$. As the heating element, nickel-chromium resistance wire is used. This choice was made due to low heat capacity of this element which allows fast starting and finishing heating. As the cooling element, 9V DC computer case fan is used. The heating and cooling circuits are two separate circuits having one input but their configurations are the same except the operation element used. In this circuit configuration, first, the input voltage is transferred using a voltage buffer for isolation purposes. Then the output of the voltage buffer is fed into the gate of a MOSFET whose drain is connected to the voltage supply through the heating/cooling element. The source of the MOSFET is connected to the ground. A large resistance between the ground and source terminals of the MOSFET is connected. This resitor is put for reliability issues, it stabilizes the amplifier. The MOSFET has opening $V_{GS,op}$ voltage as $???V$ This is compatible with the possible input voltage values. Since $V_{GS,op}$ is fairly bigger than $V_{operate}$ and smaller than V_{rest}, small discrepancies will not affect the operation of the circuit. Also, another resistance is added between the input signal and the ground to avoid a floating end when the input signal is not connected. When $V_{operate}$ is supplied, the MOSFET is out of the cut-off region. Hence, drain current is allowed to flow on it. Since the drain of the MOSFET is connected to the operation element, the operation element works for this case. When V_{rest} is supplied, the MOSFET is in the cut-off region. Hence, drain current is not allowed to flow and the operation element does not work. The overall structure can be seen in Figure 13

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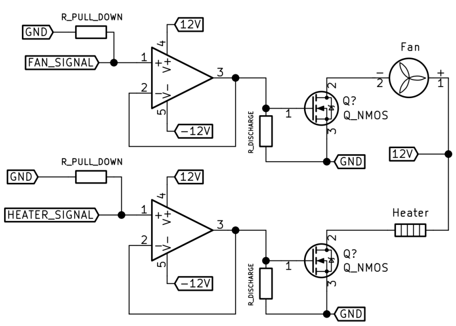


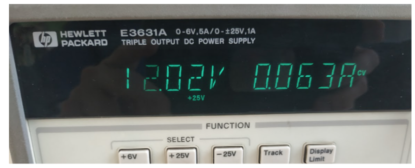
Fig. 13. Schematic of the operation unit

TABLE II
ELECTRICAL CHARACTERISTICS OF FAN AND HEATER

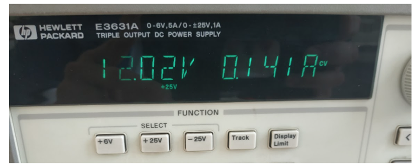
Unit Name	Current(mA)	Voltage Drop (V)	Power(W)
Fan simulated	150	12	1.8
Fan practical	78	12	0.94
Heater simulated	500	12	6
Heater practical	620	12	7.4

E. Display Unit

The aim of the display unit is to observe the desired and ambient temperature levels in a color spectrum in an analog manner given in the Figure 16. Input of this unit is both



(a)



(b)

(c)

Fig. 14. Input current & input voltage characteristics of the system when neither fan nor heater is working (a), fan is working (b), heater is working (c)

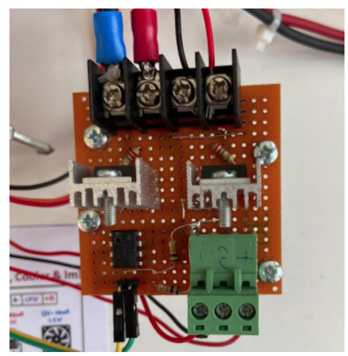


Fig. 15. Assembled operation unit

V_{set} and $V_{sensing}$. But only one of the input is considered at a time. A switch is utilized to transit between ambient and set temperature levels. In the remaining of this section, only ambient temperature will be discussed to ease the notations. It should be noted that, same operation applies to the set temperature when the swith is in the corresponding position. To achieve a continuous color spectrum, an RGB led is utilized. RGB led has three legs corresponding to blue, green and red led lig!hts whose intensities can be controlled by the current passing through them. RGB led has two versions: common cathode and common anode. [2] *niye common cathode seçildiğini açıkla

Since the current and intensity of the led lights are directly proportional, current through each three led versus the temperature graphs should be as the Figure **??**. To achieve this pattern for the red led leg, first, the circuit in Figure 17 is designed. What this circuit does it to produce a voltage level, denoted by V_{red}. Later, voltage level will be fed to the base terminal

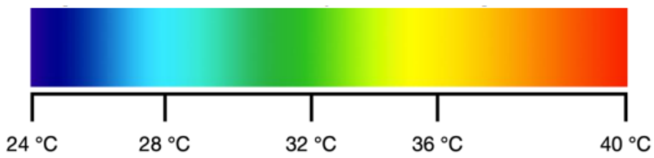


Fig. 16. Color spectrum for the display unit

of a BJT through a resistor to control the current entering the collector terminal of the BJT. The circuit in Figure 17 consists of a difference amplifier, a diode and a pull down resistor to eliminate the output when it is negative and a led to verify the positive output voltage. By using the equations 8 and 12 and inserting this into the Figure 14's temperature axis it can be seen that red led should not allow any current when the input voltage ($V_{sensing}$) is less than $4.5V$. Hence, the reference value to be substracted from the input should be $4.5V$. Output V_{red} voltage of this circuit is given in the equation 14.

$$V_{red} = \begin{cases} \frac{R?}{R?}(V_{in} - V_{ref} - 0.5V_{diode}) & \text{if } V_{red} > 0 \\ 0 & \text{o. w.} \end{cases} \quad (14)$$

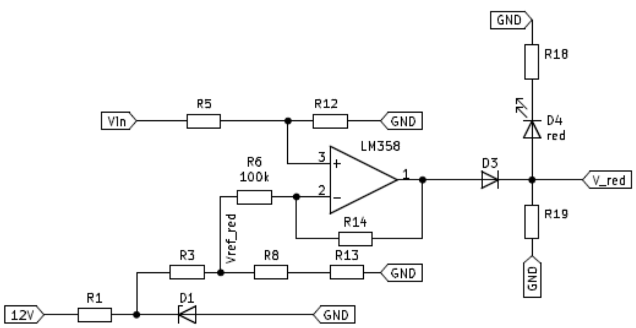


Fig. 17. Color spectrum for the display unit

A similar logic can be applied to obtain a V_{blue} voltage. This time blue led should not allow any current when the input voltage ($V_{sensing}$) is more than $4.5V$. Hence, the circuit in the Figure 18 is constructed to obtain V_{blue} to be fed to the base terminal of a BJT. In this circuit everything is the same with the circuit in Figure 17 expect the direction of the subtraction in the difference amplifier. Output V_{blue} voltage of this circuit is given in the equation 15.

$$V_{blue} = \begin{cases} \frac{R?}{R?}(V_{ref} - V_{in} - 0.5V_{diode}) & \text{if } V_{blue} > 0 \\ 0 & \text{o. w.} \end{cases} \quad (15)$$

For the current going through the green leg, we do not have a zero current region like in the blue and red legs, hence, it is difficult to implement that current level in a similar manner. But note that, the total amount of current flowing through the all three legs are equal for all temperatures. Hence current

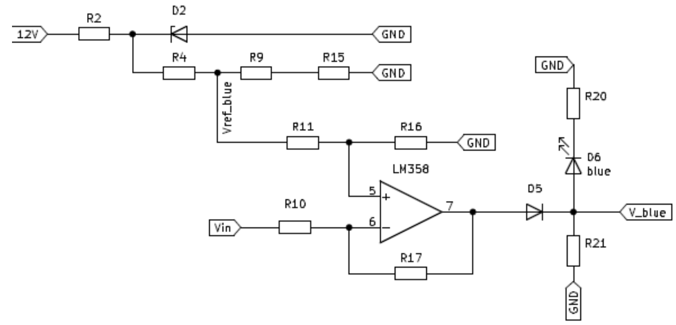


Fig. 18. Color spectrum for the display unit

through the red leg can be computed as $I_{ref} - I_{red} - I_{blue}$ where I_{red} and I_{blue} are denoting the current through the blue and red legs respectively and the I_{ref} can be found in Figure **??**.For this purpose, the circuit in the Figure **??** is constructed. This circuit acts like an ideal current source with value $curentvalueintermsofR$. The final circuitry of this unit can be seen in Figure 19. As explained before, V_{red} and V_{blue} voltages are fed to a base of a BJT whose emitter is connected to the ground and collector is collected to the red and green legs of the RGB led. This configuration provides a linear increase in the collector current with respect to the V_{red} and V_{blue}. Here, $R22$ is chosen such that $15mA$ of current will pass the collector of $Q1$ when then $V_{red} = 10V$. A similar choice of $R29$ is also valid. With supplying the reference current value to the overall RGB, current through the green leg is arranged. Here, it should be noted that there are actually two voltage drops on V_{red} and V_{blue}. First one is coming from the opening voltage of the diode in Figures **??** and **??** which are also explained in the equations 15 and 14. Second one is the opening voltage of the BJT in the Figure 19. Hence, with the 4.5 V of reference voltage is not enough, the reference voltages should be determined so that these voltage drops are taken into account.

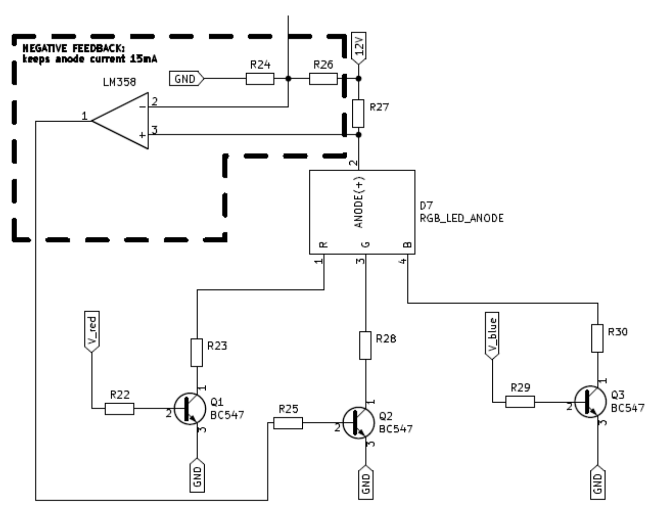


Fig. 19. Color spectrum for the display unit

*kullanılan mosfet ve opamp çeşitlerini belirt
*opampte iki opamp olduğunu belirt
*simulation results
*experimental results

The input output relations of the units can be seen in Figure 20.

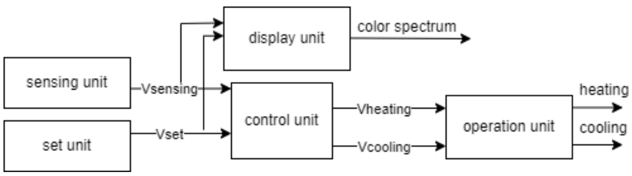


Fig. 20. Color spectrum for the display unit

IV. Conclusion

References

[1]
[2]