# Analog Design Approach For A Micro Air Conditioner


Mustafa Mert MIHCI
Electrics & Electronics Engineering Department
Middle East Techincall University
Ankara, Turkiye
mert.mihci@metu.edu.tr

Ahmet Ugur AKDEMIR
Electrics & Electronics Engineering Department
Middle East Techincall University
Ankara, Turkiye
akdemir.ahmet@metu.edu.tr



***Abstract*— This paper introduces the analog design and implementation of a simple, effective, autonomous micro-air conditioner capable of performing both heating and cooling operations. The analog design strikes a balance between functionality and simplicity, providing a solution for precise and reliable temperature regulation.**


***Index Terms*— Analog Micro-Air Conditioner, heating, cooling, temperature control**

## I. Introduction

This project focuses on the design and implementation of a micro-air conditioner system designed for small spaces by using analog circuit elements. The system operates both heating and cooling functionalities and is composed of a control unit, display unit, sensing unit, and operation unit. The control unit, featuring decision and function subunits, manages the comparison between ambient and desired temperatures. The operation unit, responsible for heating and cooling, employs a stone resistor for heating and a DC electric fan for cooling. The sensing unit incorporates an analog temperature sensor to relay ambient temperature information to the control unit. The display unit contains an RGB LED and a switch to show set or ambient temperature levels continuously across the visible spectrum. In this paper, the details of design and implementation of this project as well as the simulation and experimental results will be discussed.

## II. Problem definition

As stated above, we are asked to design and simulate a micro air conditioner model that operates heating & cooling operations in certain conditions. Design specifications of a micro air conditioner include modularity for individual testing, a temperature range of 24°C to 40°C, RGB LED indicators covering the visible spectrum for both ambient and set temperature, potentiometer-adjusted set value. It will compare the ambient temperature with the desired temperature. If the ambient temperature is higher than the desired temperature, it operates in the cooling mode. Otherwise, it operates in the heating mode. The design also must be capable of delivering at least 3W power to the heating unit.

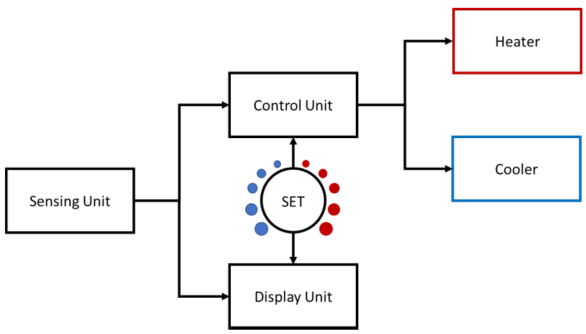


*Fig. 1. The block diagram of the project*

The block diagram of the overall project is shown in Fig. 1.

## III. Desing methodology

In this part, the methodologies of the units are discussed. Also, the simulation results obtained in LTspice are discussed.

### A. Sensing Unit

The sensing unit is employed for measuring ambient temperature and incorporates the "LM35" temperature sensor. This sensor provides temperature readings in °C, generating a 10mV output for each 1°C change. LM35 has three terminals, illustrated in Fig. 2.


*Fig. 2. LM35 pinout*

The first terminal from left when its flat surface is faced towards you is connected to a 12 V DC voltage source, the second terminal is the output terminal with the characteristics mentioned above, and the third terminal is the grounded terminal. The second element in the sensing unit is a non-inverting amplifier, shown in Fig. 3. utilizing an LM741 Op-Amp with $R_f = 51\ k\Omega$ and $R_1 = 5.6\ k\Omega$

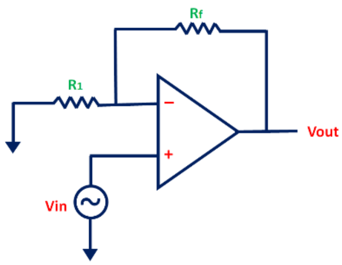


*Fig. 3. The circuit diagram of non-inverting amplifier.*

The resistor values were chosen to achieve a 10 V/V gain, necessary for comparing the voltage obtained from the sensing unit with the voltage derived from the set temperature value. This is expressed in (1):

$$A_V = 1 + \frac{R_2}{R_1} = 1 + \frac{51\ k\Omega}{5.6\ k\Omega} \cong 10\ {}^{V}/_{V} \tag{1}$$

The output voltage of LM35, ranging from 240 mV to 400 mV, representing temperatures between 24°C and 40°C, needs to be scaled by a factor of 10. Consequently, we successfully achieve the desired temperature measurement and representation as required.

## B. Set Unit

The Set Unit serves the purpose of defining the desired temperature through the integration of two resistors, a POT, and a buffer amplifier. With a designated set temperature range of 24°C to 40°C, corresponding to voltage values between 2.4V and 4V established by the sensing unit, a voltage division circuit is used to achieve the necessary voltage range from a 12 V DC supply. The circuit involves resistors of 75 kΩ and 39 kΩ, along with a POT ranging from 0.9 kΩ to 100 kΩ. Equations (2), (3) and (4) are given below to show how this desired voltage range is obtained.

$$V_{SET} = \frac{39\ k\Omega}{39\ k\Omega + 75\ k\Omega + R_{POT}} \cdot V_{Supply} \tag{2}$$

$$V_{SET,MIN} = \frac{39\ k\Omega}{39\ k\Omega + 75\ k\Omega + 100\ k\Omega} \cdot 12\ V \cong 2.19\ V \tag{3}$$

$$V_{SET,MAX} = \frac{39\ k\Omega}{39\ k\Omega + 75\ k\Omega + 0.9\ k\Omega} \cdot 12\ V \cong 4.07\ V \tag{4}$$

To preserve signal integrity and mitigate power loss, an LM741 operational amplifier (op-amp) with unity gain, depicted in Fig. 4., is incorporated as the buffer amplifier. This op-amp ensures that the set voltage remains undistorted and stable throughout the system.

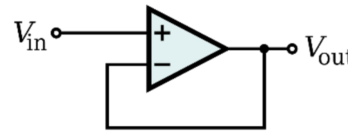


*Fig. 4. The circuit diagram of buffer.*

Through this design, we successfully represent any set temperature within the specified range of 24°C to 40°C as voltage signals ranging from 2.4V to 4V, aligning with the project design requirements.

## C. Control Unit

The control unit consists of two subunits: the decision subunit and the function subunit. The decision subunit measures the difference between the set temperature and the ambient temperature, employing a difference amplifier with unity gain as illustrated in Fig. 5. The difference amplifier has the output relation given in (5). To obtain unity gain, $R_1 = R_2 = 1\ k\Omega$ is chosen.

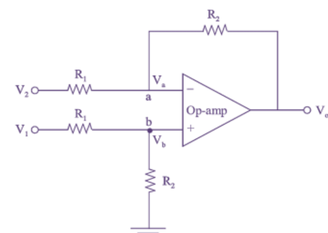


*Fig. 5. The circuit diagram of difference amplifier*

$$V_{out} = \frac{R_2}{R_1} \times (V_1 - V_2) \tag{5}$$

The non-inverting terminal of the LM741 op-amp is connected to the output of the sensing unit, representing 10 times scaled output of the LM35 temperature sensor. The inverting terminal is connected to the output of the set unit, which is the output terminal of the buffer amplifier with unity gain. This difference amplifier effectively computes the temperature difference and produces it as an output.

The function subunit is designed to initiate and indicate operations determined by the decision unit. It incorporates two comparators by using 2 LM741 op-amp, two n-channel MOSFETs, and two LEDs. The detailed configuration is shown in Fig. 6.

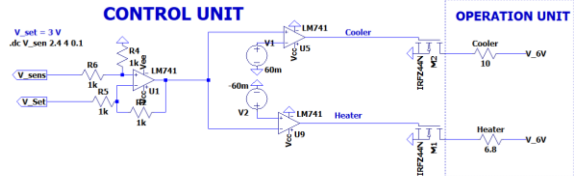


*Fig. 6. The overall LTspice circuit of the control unit*

This unit takes the output of the decision unit as input and directs it to the comparators. Utilizing a single op-amp, the comparators compare the input with a 60mV reference voltage, achieved through voltage division from a 12V DC source given in (5).

$$60\ mV \cong \frac{5.1\ k\Omega}{5.1\ k\Omega + 1\ M\Omega} \cdot 12\ V \qquad (6)$$

This reference voltage introduces a dead band, ensuring both the heater and cooler units remain off. The +SAT terminals of comparators connect to the 12 V DC supply, while the -SAT terminals connect to the -12 V DC supply.

The non-inverting terminal of the comparator controlling the cooler is linked to the input, and its inverting terminal is connected to the reference voltage. If the input signal exceeds the reference voltage, the comparator provides its +SAT Voltage as output. This activates the cooler by creating a voltage difference between the gate and source terminals of the IRFZ44N model n-channel MOSFET. This voltage difference lets a current flow through the MOSFET's drain terminal, powering the cooler and a blue LED for indication.

The non-inverting terminal of the comparator controlling the heater is connected to the reference voltage, and its inverting terminal is linked to the input. If the input signal falls below the reference voltage, the comparator produces its +SAT Voltage as output. This initiates the heater by creating a voltage difference across the gate and source terminals of the IRFZ44N model n-channel MOSFET. This voltage difference results in a current flow through the MOSFET's drain terminal, powering the heater and a red LED for indication.

Through the integration of these two subunits, an effective control unit is achieved. This unit determines whether the ambient temperature is higher or lower than the set temperature and takes appropriate actions accordingly. The use of MOSFETs for switching ensures efficient control of the cooler and heater units in response to the output of the decision unit output. Additionally, for comparators, an integrated op-amp LF347N is utilized, and for the difference amplifier, an op-amp LM741 is employed.

The simulation results of the control unit when the set voltage is 3.2 V are given in Fig. 7. From this figure, the results are sufficient for the design.

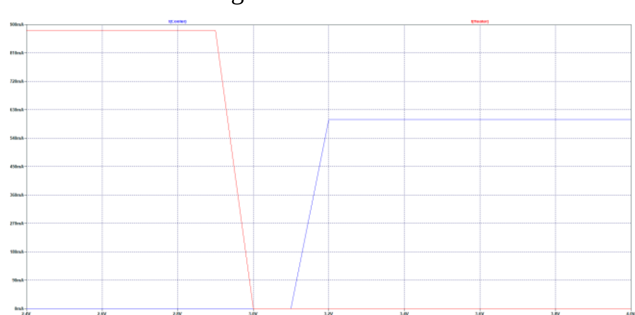

*Fig. 7. The LTspice simulation results of the control unit*

## D. Operation Unit

The operation unit constitutes the physical response of the entire system and is comprised of two subparts: the heater and the cooler. The heater is implemented as a 6.8 Ω stone resistor, chosen for its capability to handle higher current values. One end of the stone resistor is connected to a 6 V DC source, while the other end is linked to the designated drain terminal. This choice of a 6 V DC source for the stone resistor allows for the attainment of higher current values, such as 5 A, compared to the 12 V DC source, which is limited to 1 A. Meeting the requirement to deliver at least 3W power to the stone resistor is verified as shown in (7).

$$P_H = {I_H}^2 \times R_H = (0.88)^2\ A \times 6.8\ \Omega \cong 5.27\ W\ > 3\ W \quad (7)$$

The cooler is implemented as a 5V DC fan with a rated current of 0.2 A. One end of the cooler is connected to the 6V DC supply, and the other end is connected to the mentioned drain terminal, utilizing the same 6V supply logic as the heater. This ensures consistent and efficient operation of both the heater and cooler components within the specified system parameters.

## E. Display Unit

The purpose of the display unit is to show the set and ambient temperature according to the color spectrum given in Fig. 8. The input of this unit is the set voltage from the set unit, $V_{set}$, or the ambient temperature from sensing unit, $V_{ambient}$. Transition between these voltages corresponding to the temperatures is obtained by using a three-legged switch. In the rest of this part, $V_{input}$ is used to represent the input of this unit as this unit is working independent of the type of the input.

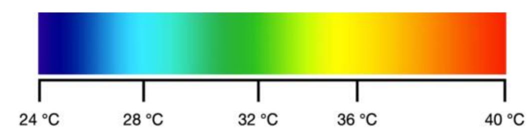


*Fig. 8. Temperature and color spectrum*

The display unit contains a common cathode RGB LED and a switch to show the temperature. As the brightness of each LED in the RGB LED is proportional to the current flowing through it, the voltage across the LED, hence the current, is controlled. The display unit covers the visible spectrum continuously by controlling the currents flowing through blue, red and green LEDs according to the corresponding voltage of the temperature in the range 2.4 V to 4 V corresponding to 24 °C and 40 °C respectively. The desired current versus temperature graph is given Fig. 9.

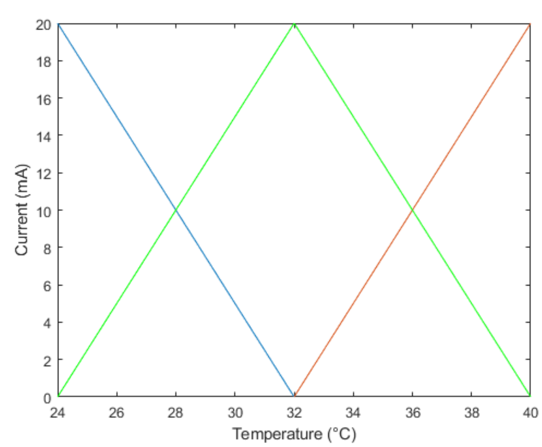


*Fig. 9. The desired temperature vs current graph for each LED*

To achieve this, three differential amplifiers and one summing amplifier are used. A differential (or difference) amplifier is a two-input circuit that amplifies only the difference between its two inputs. A differential amplifier is shown in Fig. 5. A non-inverting summing amplifier is an electronic circuit that combines multiple input voltages to produce an output voltage that is proportional to the algebraic sum of its input voltages given in Fig. 10. The output voltage of a non-inverting summing amplifier is given in (8). In the design, $R_1 = R_2 = R_a = R_f = 1\ k\Omega$ is chosen; hence, the output relation reduces to (9).

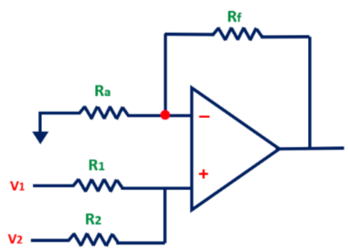


*Fig. 10. The circuit diagram of non-inverting summing amplifier.*

$$V_{out} = (1 + \frac{R_f}{R_a}) \times \left(\frac{R_2}{R_1 + R_2} V_1 + \frac{R_1}{R_1 + R_2} V_2\right) \qquad (8)$$

$$V_{out} = V_1 + V_2 \qquad (9)$$

To obtain the desired current vs temperature graph for blue and red LED, a reference voltage, $V_{ref}$, which is 3.2 V is needed. To obtain this reference voltage, a voltage division from 12 V and a unity gain buffer amplifier is used shown in Fig. 11 and (10).

$$V_{ref} = 12 \times \frac{120\ k\Omega}{120\ k\Omega + 330\ k\Omega} = 3.2\ V \qquad (10)$$

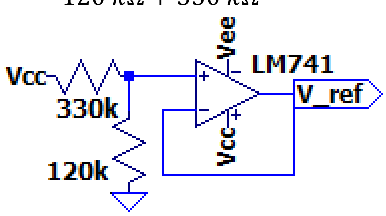


*Fig. 11. The voltage division circuit for reference voltage.*

For blue LED, $V_{ref}$ is connected to the non-inverting input ($V_+$) and $V_{in}$ is connected to the inverting input ($V_-$) of the differential amplifier op-amp with gain 12. This gain value is choosen such that the current graph of blue and green LEDs intersect at 2.8 V corresponding to the color cyan at 28 °C. The negative supply terminal of the op-amp ($V_{EE}$) is connected to the ground to eliminate negative output voltages when the $V_{in}$ is greater than $V_{ref}$. In the other hand, when $V_{ref}$ is greater than $V_{in}$, the output that is connected to the blue LED leg of the RGB LED is decreasing with the slope (gain) mentioned above. Also, a resistor value $R_{blue} = 560\ \Omega$ is connected in series with the blue LED to limit the current following through LED and not to damage the RGB LED. The overall circuit for blue LED is shown in Fig. 12.

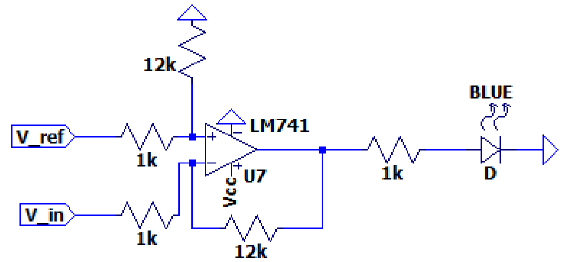


*Fig. 12. The overall LTspice circuit of blue LED.*

For red LED, $V_{ref}$ is connected to the inverting input ($V_-$) and $V_{in}$ is connected to the non-inverting input ($V_+$) of the differential amplifier op-amp with gain 12. This gain value is choosen such that the current graph of red and green LEDs intersect at 3.6 V corresponding to the color yellow at 36 °C. The negative supply terminal of the op-amp ($V_{EE}$) is connected to the ground as well. When $V_{ref}$ is less than $V_{in}$, the output that is connected to the red LED leg of the RGB is increasing with the slope (gain) mentioned above. Also, a resistor value $R_{red} = 560\ \Omega$ is connected in series with the red LED to limit the current following through LED and not to damage the RGB LED. The overall circuit for red LED is shown in Fig. 13.

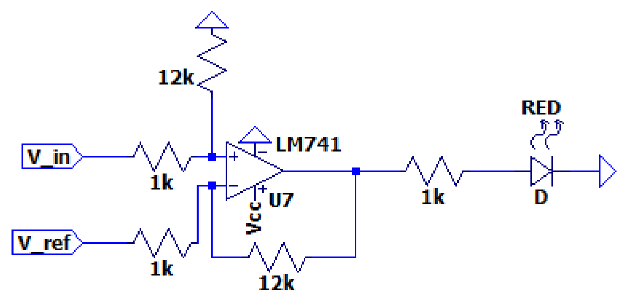


*Fig. 13. The overall LTspice circuit of red LED.*

For green LED, the output voltages of the blue and red circuits are summed by using a non-inverting summing amplifier mentioned above. Then, this sum of the voltages is subtracted from 12 V by using a unity gain differential amplifier. The overall circuit for green LED is shown in Fig. 14. Also, a resistor value $R_{green} = 560\ \Omega$ is connected in series with the blue LED to limit the current following through LED and not to damage the RGB LED.

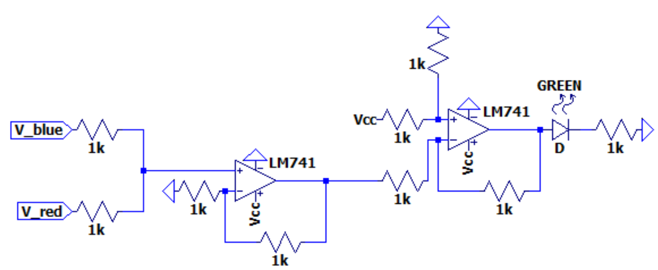


*Fig. 14. The overall LTspice circuit of green LED.*

The overall circuit and its simulation results are given in Fig. 15. and Fig. 16. respectively.

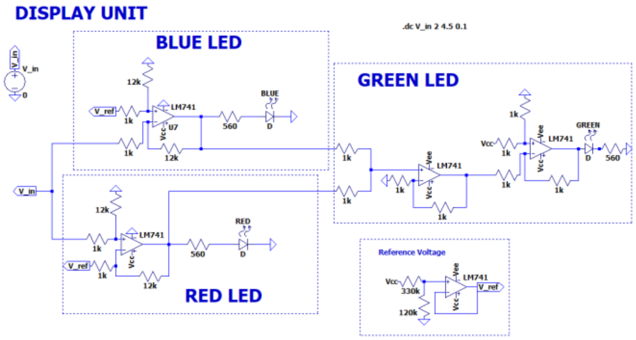


*Fig. 15. The overall LTspice circuit of the display unit.*

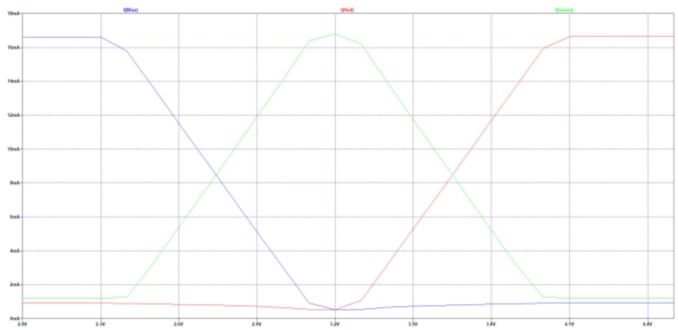

*Fig. 16. The LTspice simulation results of the display unit*

From Fig. 16., the result of the display unit is sufficient for this design project.

## IV. Experimental Results and Comparison with Simulation Results

In the preceding sections, theoretical foundations and LTspice simulation results of the design are discussed. The simulation results aligned seamlessly with our initial design specifications. However, upon transitioning from simulation to real-world implementation, we encountered challenges that necessitated adjustments. Initially, our intention was to operate within the millivolt (mV) range. Unfortunately, practical applications introduced complications such as offset voltages from the non-ideal LM741 op-amps and voltage drops across the wires used on the breadboard. Also, we have observed that when the resistance of the stone resistor is around 3-5 Ω, it draws approximately 1.5 A current from the +6 V terminal of the DC supply. This high current affects the overall performance of the design, for example the voltage values that are obtained by voltage division are changed since the ground voltage of the overall circuit changes due to the high current from the supply. Hence, the display unit does not work as expected. To solve this problem, we have increased the resistance of the stone resistor to 10 Ω. However, in this case, the criterion of delivering at least 3 W power is not satisfied. Then, we tried a 6.8 Ω stone resistor and obtained the optimum results for the control and the display unit. In this case, 0.66 A is drawn from the power supply when the heater is working which satisfies the at least 3 W power criterion. The other problem we have faced during the project is that when the temperature of the sensing unit gets closer to the set temperature, the current flowing through the stone resistor decreases. This prevents the LM35 temperature sensor from reaching its maximum temperature of 40 °C. To solve the problem, the LM35 is placed on the surface of the stone resistor. After solving those problems, we tested the design for other criteria of the project and observed that the design works properly according to the criteria.

## V. Conclusion

In conclusion, the analog micro-air conditioner project presented in this report successfully addresses the design and implementation of a compact and versatile system capable of both heating and cooling operations. Throughout the report, the design methodologies, circuit diagrams, and simulation results in LTspice are meticulously detailed. The simulations demonstrate the effectiveness of each unit. However, the transition from simulation to real-world implementation revealed practical challenges, such as offset voltages and high current demands, which required adjustments to components like the stone resistor. Despite these challenges, the final implementation of the micro-air conditioner successfully met the project criteria after careful troubleshooting and adjustments. The system now operates within the specified temperature range, ensuring precise and reliable temperature regulation for small spaces. This project underscores the importance of considering practical challenges in real-world applications, demonstrating the resilience of the design team in overcoming obstacles to deliver functional and practical projects.

## References

[1] Texas Instruments. (2017, December). LM35 Precision Centigrade Temperature Sensors Datasheet. Texas Instruments Symlink. Retrieved February 10, 2022, from https://www.ti.com/lit/ds/symlink/lm35.pdf