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## DESIGN OF AN AUTOMATIC TEMPERATURE CONTROLLED SWITCH FOR AIR-CONDITIONING SYSTEMS

By

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### ABSTRACT

*Due to relatively wide range of atmospheric temperature variation within a day in some part of Nigeria, the need for manual control of cooling and heating devices within an enclosure (homes or offices) becomes obvious. This manual control is distractive, tiring and unsatisfactory and above all, increases wear and tear of switches, these calls for introduction of automatic temperature control device. This device therefore provides automatic inter-switching requirements for air-conditioner and room heating systems in accordance with changes in atmospheric condition using discrete electronic components. It also provided with sensitivity controls to suit individual and environmental differences. Based on the accurate and detailed derivation of component values at all stages of the design, it is expected to exhibit satisfactory performance on implementation.*

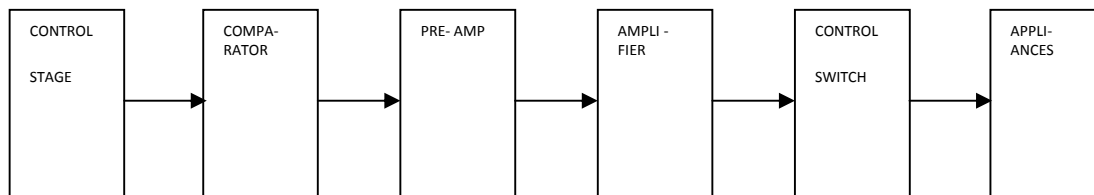
### INTRODUCTION

Engineering technology has witnessed rapid development in the last five decades or thereabout. That rapid development is transforming our society and influencing it in no small way. The use of automatic control and automation systems has enhanced the transformation of human life style from labour intensive life style to automation life style. Hence, it has become out-fashioned to manually control devices that could be controlled automatically.

Air conditioners and room heaters are two devices that are helping in normalizing/controlling enclosure temperature in places where such devices are needed, and particularly in areas where there is large variation

in daily/yearly temperature change. In most part of Nigeria, only one of the devices (air conditioner) is applicable while in some part like Gembu in Taraba state, and Jos in Plateau state room heater is desirable due to the low atmospheric temperature almost the year round. However, there exist few places in the country in which temperature change between 15<sup>0</sup>C to 40<sup>0</sup>C occurs almost on daily basis (Ishaya M. S., 1999), thus the need for an automatic temperature controlled switch for air-conditioning systems (air conditioners and room heaters) to help in automatically adjusting room temperature to a pre-determined temperature level or the ambient temperature.

The design has three operational states viz: air-conditioner ON room-heater OFF, room-heater ON air-conditioner OFF, and air-conditioner OFF room-heater OFF designated as state 1, state 2 and state 3 respectively. In addition to these states of operation, it has sensitivity control that allows for manipulation of the design in order to support ergonomic, that is, it can be made to remain in the first two states for as long as desired, vary the operating temperature of the two devices and be retained in the third state when the ambient temperature is 25<sup>0</sup>C.



**Figure 1:** Functional block diagram of the device

### *The Control Stage*

The control stage is a bridge network with thermistors as the control component and having resistors (invariable and variable) functioning as voltage level divider and sensitivity controls respectively. The control stage works as a voltage divider network and the components values are determined to ensure operation in the other three sections.

### *The Comparator Stage*

The comparator stage uses two similar operational amplifiers with equal voltage (magnitude) inputs but at alternate input points thereby making sure that only one of the three states of operation is achieved at a time. The input to this stage comes from the bridge network functioning as temperature controlled stage owing to the presence of a temperature dependent resistor (thermistor) in the bridge.

### **FUNCTIONAL STAGES OF THE DEVICE**

Apart from the power supply stage, the design is primarily divided into four sections namely: the control unit, the comparator unit, the amplification unit, and the switching control unit. This is shown in figure 1 in the form of a block diagram. Furthermore, there are some adjoining components such as indicators for operational assurance. The subsequent sections detailed the operation of the stages. The detail design of all the stages is shown in section three.

### *The Amplification Stages*

The amplification stages here refer to both the pre-amplification and amplification stages, occasioned by the usually small current output of operational amplifier which if not amplified will be insufficient to energize the 20A rated electrical relay required to drive the high current rating of the appliances (air-conditioners and room heaters) to be controlled. Consequent upon this, the current pre-amplification (driver) and current amplification stages became necessary.

The current pre-amplification stage consists of NPN Bipolar transistor whose collector current is rated at 2mA with average gain (current) of 400 and followed by the amplification stage having an NPN Bipolar power transistor rated at 10A collector current. This is deliberate in order to be able to drive the electrical relay. A bipolar transistor is chosen to exploit its low input impedance characteristic hence maximum power

transfer is obtained from the comparator stage to the amplification stage being that an operation amplifier has low output impedance.

The transistors are biased to operate in linear and cut-off regions as shown in figure 2 since they are essentially needed in this design for amplification and switching purposes. The relays are connected on the power transistor and being an inductive device a rectifying diode is connected in parallel with the relay coil to prevent back e.m.f. current as stated in Lenz's law (Jimmie J. C., 1990). The flow of back e.m.f. through a semiconductor device damages it owing to thermal runaway (effect of heat on transistor's gain). The diode conducts the back e.m.f. during which power is

dissipated in form of heat owing to resistance of the diode ( $R = P/I$ ).

More so, at turn-off, a very high transient voltage ( $V = Ldi/dt$ ) is developed at the contact point, which in this case is the node where the transistor's collector is connected to the anode of the diode and together with the second terminal of the inductor. Without the diode, this voltage will simply damage the transistor, and any other semiconductor component having junction breakdown voltage. The diode comes to the rescue as it is forward biased by the voltage and its low forward bias resistance enables almost all the current to flow through the diode where it is totally dissipated or decayed at the expiration of the transient period.

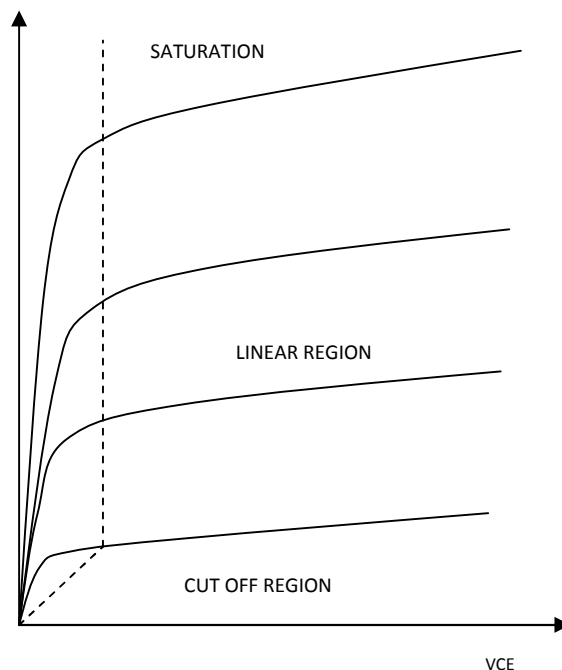


FIGURE 2: TRANSISTORS

### *The Switching Control Stage*

The Switching control stage comprise of the electrical relays rated at 20A, normally open (NO)

contact, with its coil resistance ( $R_l$ ) replacing collector resistance ( $R_c$ ). The relay contacts are connected as switches on the supply mains which are then connected to a 15A rated socket switches where the devices

intended to be controlled are connected. There are also A.C. and D.C. voltage indicators.

**SYSTEM DESIGN**

The design primarily comprises of four independent stages, which are: the control stage, the comparator stage, the amplification stage and the switching control stage. The design is expected to control air conditioner and room heater powered with alternating current (A.C.) rated at 240 V and 15A. It is expected to be biased by a 12V rectified and regulated D.C. voltage. What follows is the stage-wise implementation of the design.

**Control Stage Design**

Starting with the characteristics of the thermistor used in the design; being a major component in the design, the thermistors, designated as RT1 & RT2 in figure 3 have the following characteristics (R. S. Component, 1995):

- Operating temperature range: -5°C to 70°C
- Resistance range: 1kΩ to 20 kΩ
- Resistance at 25°C: 4.7 KΩ

Design consideration: Since the design is expected to be in stage 3 at 25°C being the normal temperature in which most people do not need neither air conditioner nor room heater, then R<sub>1</sub> and R<sub>2</sub> is chosen to be 4.7 kΩ. Therefore, RV1 = RV2 in figure 3 should be set at 0Ω.

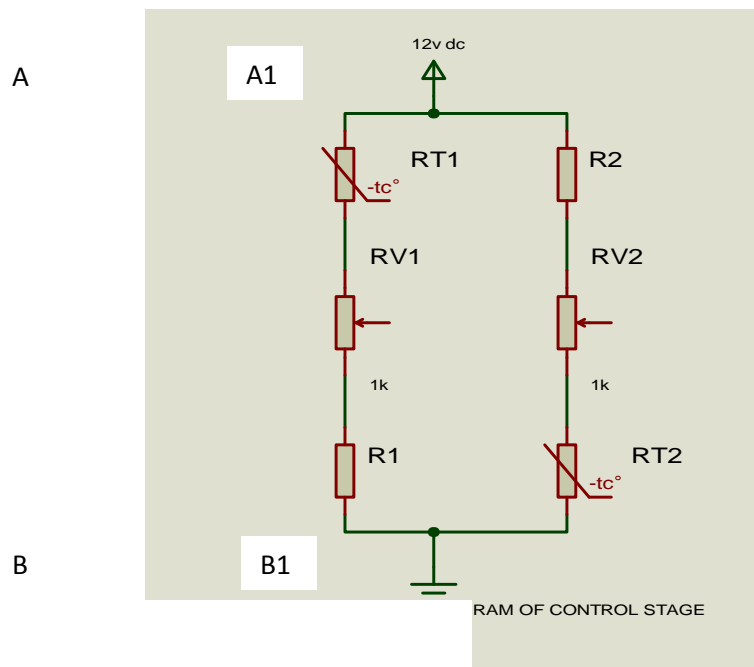


Figure 3: Schematic diagram of control stage

**State I Operation: Ambient Temperature > 25°C**

$$RT1 = RT2 < 4.7K\Omega$$

Assuming temperature is typically 40°C,

$$RT1 = RT2 = 4K\Omega$$

(a) Using voltage divider's rule with respect to nodes A and B

$$V1 = \frac{R1V_{cc}}{R1 + RT1} = \frac{(4.7 \times 10^3) \times 12}{(4.7 \times 10^3) + (4 \times 10^3)} = 6.483V$$

(b) Using voltage divider's rule with respect to nodes A1 and B1

$$V2 = \frac{RT2V_{cc}}{RT2 + R2} = \frac{(4 \times 10^3) \times 12}{(4 \times 10^3) + (4.7 \times 10^3)} = 5.517V$$

### Stage 2 Operation: Ambient Temperature < 25°C

$$RT1 = RT2 > 4.7K\Omega$$

Assuming temperature is typically 15°C,

$$RT1 \text{ and } R > 8K\Omega$$

(a) Using voltage divider's rule with respect to nodes A and B

$$V1 = \frac{RT1V_{cc}}{R1 + RT1} = \frac{(4 \times 10^3) \times 12}{(4 \times 10^3) + (4.7 \times 10^3)} = 6.483V$$

(b) Using voltage divider's rule with respects to nodes A1 and B1

$$V2 = \frac{RT2V_{cc}}{RT2 + R2} = \frac{(8.8 \times 10^3) \times 12}{(8.8 \times 10^3) + (4.7 \times 10^3)} = 7.822V$$

### Stage 3 Operation: Ambient Temperature is 25°C

$$RT1 = RT2 = 4.7K\Omega$$

Using voltage divider's rule:

(a) Using voltage divider's rule with respect to nodes A and B

$$V_1 = \frac{RT1V_{cc}}{R1 + RT1} = \frac{(4.7 \times 10^3) \times 12}{(4.7 \times 10^3) + (4.7 \times 10^3)} = 6V$$

(b) Using voltage divider's rule with respects to nodes A1 and B1

$$V_2 = \frac{RT2V_{cc}}{RT2 + R2} = \frac{(4.7 \times 10^3) \times 12}{(4.7 \times 10^3) + (4.7 \times 10^3)} = 6V$$

Since  $RT$  varies from  $4 \text{ k}\Omega$  to  $8.8 \text{ k}\Omega$  within temperature range of  $40^\circ\text{C}$  to  $15^\circ\text{C}$ , the difference in resistance of the two extreme is  $4.8 \text{ k}\Omega$  hence,  $RV$  (sensitivity adjust) will be chosen to either delay or quicken the operational stages, and the value chosen should be around the difference in  $RT$ , thus,  $RV$  ranges from  $0\Omega$  to  $5 \text{ k}\Omega$ .

### The Comparator Stage Design

The Operational Amplifier (Op-amp) used is a dual differential amplifier (LF 3553N) with Gain

(A) of 110. Hence,  $V_o = A_{Vd} = A(V_1 - V_2)$

However, note that the highest voltage magnitude (saturation voltage) of an Op-amp is approximately  $2V$  less than the power supply voltage. Thus,  $V_o$  varies from  $V-2$  to  $-V+2$  designated as  $V_{O1}$  and  $V_{O2}$  respectively. The circuit diagram of the comparator is shown in figure 4

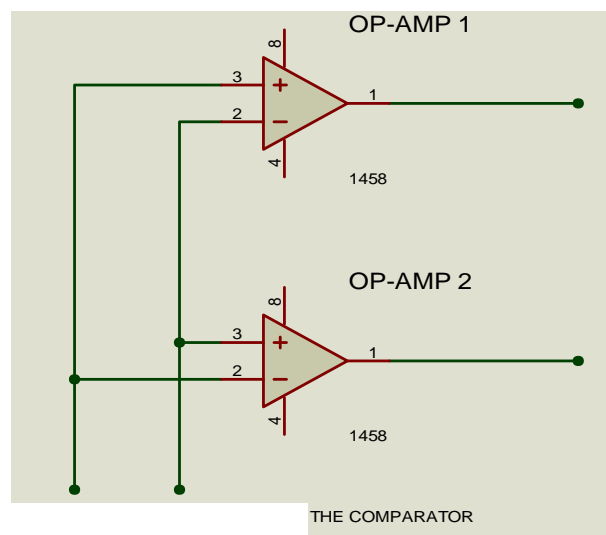


Figure 4: Circuit diagram of the comparator

**State 1 Operation:**

$$V_d = V1 - V2 = 6.483V - 5.517V = 0.966V$$

$$V_{O1} = AV_d = 110 \times 0.966V = 109.56V$$

$$V_{O2} = AV_d = 110 \times 0.966V = 109.56V$$

Since  $V_{cc} = 12V$  and  $V_{sat} = V_{cc} - 2$  or  $-V_{cc} + 2$

$$V_{O1} = 12 - 2 = 10V$$

$$V_{O2} = -12 + 2 = -10V$$

Hence,  $V_{O2sat} = 10V$

**State 2 Operation:**

$$V_d = V1 - V2 = 4.178V - 7.822V = -3.644V$$

$$AV_d = 110 \times (-3.644)V = -400.84V$$

Since  $V_{cc} = 12V$  and  $V_{sat} = V_{cc} - 2$  or  $-V_{cc} + 2$

$$V_{O1} = -12 + 2 = -10V$$

$$V_{O2} = 12 - 2 = 10V$$

Hence,  $V_{O1sat} = -10V$

**State 3 Operation**

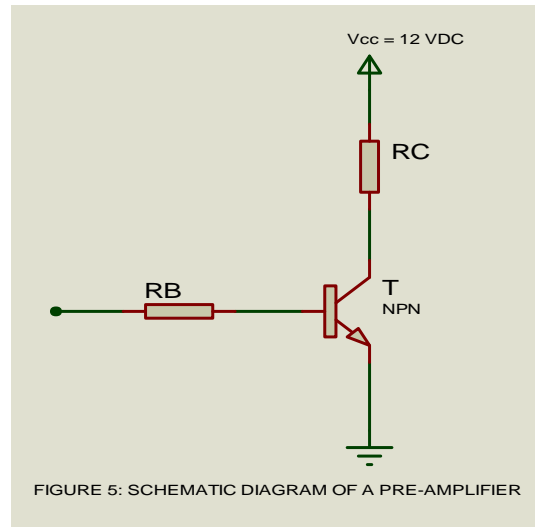
$$V_d = V1 - V2 = 6V - 6V = 0V$$

Hence  $AV_d = 0V$

Since there was no differential voltage at the input,  $V_0$  is zero and  $V_{Osat}$  is at ground. This makes the base-emitter junction to be at the same potential, hence no operation at the last two stages of amplification.

***The Pre-Amplification and Amplification Stages Design***

For a transistor to function as an amplifier, it has to operate within the linear region where neither  $V_{cc}$  nor  $I_c$  goes to  $0V$  (Paul H. & Winfield H., 1989). The schematic diagram of the typical amplifier is shown in 5.



**Figure 5:** Schematic Diagram of a pre-amplifier

$$12 = 2 \times 10^{-3} \times R_C + 5$$

$$R_C = \frac{12-5}{2 \times 10^{-3}}$$

$$R_C = 3.5K\Omega$$

$$V_B = I_B R_B + V_{BE}$$

$$I_B = \frac{I_C}{\beta} = \frac{2 \times 10^{-3}}{200} = 10\mu A$$

$$V_B = V_{0sat} = 10V$$

$$V_{BE} = 0.7V$$

$$V_{BE} = 930 K\Omega$$

### **Controlling Switch Stage Design**

For a transistor to function for switching purposes, it has to be operated at either of the saturation region or the cut-off region. During saturation  $V_{CE} = 0$  therefore,  $V_{CC} = I_C R_C$  and at cut-off region  $I_C = 0$  hence,  $V_{CC} = V_{CE}$ . For this device, at saturation the system is ON and at cut-off the system is OFF (Adediran Y. and Kukoyi O., 1992).

#### **3.4.1 Cut-off Analysis**

$$I_C = \beta I_B \quad \dots (i)$$



$$V_O = I_B R_B + V_{BE} \quad \dots (ii)$$

$$I_B = \frac{V_O - V_{BE}}{R_B} \quad \dots (iii)$$

$V_{BE}$  is the voltage required to forward bias the base-emitter junction and its source is  $V_O$  from equation (ii). At any voltage  $\leq V_{BE}$  there will be no conduction and the source is better considered as zero. Hence  $-V$  to  $0.3V$  for germanium material is as good as zero volts (0V), and  $-10V$  to  $0.65V$  for silicon material is considered zero volts (0V). From equation (i),  $I_C = 0A$  when  $V_O = 0$  or the Op-amp is at the inverting state, that is,  $V_O = -10V$ . Considering  $I_C = I_B$  for zero base current ( $I_B$ ),  $I_C = 0A$ . Again considering the transistor output equation:

$$V_{CC} = I_C R_C + V_{CE}$$

$$\text{for } I_C = 0,$$

$$V_{CC} = V_{CE}$$

This implies that  $V_{CC}$  appears below the relay or no current passes through the relay thereby no operation, hence, both the cooling and heating systems are in OFF state.

### **Saturation Analysis**

At saturation,  $I_C$  is maximum and  $V_{CE}$  minimum. In this case  $V_{CE}$  is assumed zero volts.

$$\text{From } V_{CC} = I_C R_C + V_{CE}$$

$$\text{At } V_{CE} = 0V,$$

$$V_{CC} = I_C R_C$$

Therefore,  $I_C = \frac{V_{CC}}{R_C}$  which is  $I_C$  maximum or at saturation

$$\therefore I_{C\text{sat}} = \frac{V_{CC}}{R_C} = \frac{12}{168 \times 10^3} = 71.4\text{mA}$$

$$\text{Since } I_C = \beta I_B$$

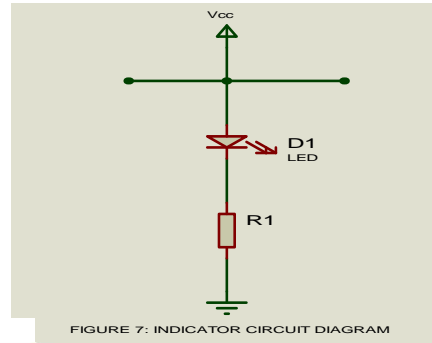
$$I_{B\text{sat}} = \frac{71.4 \times 10^{-3}}{37.5} = 1.9\text{mA}$$

$$\text{From } V_O = I_B R_B + V_{BE}$$

$$R_E = \frac{V_O - V_{BE}}{R_C} = \frac{10 - 0.7}{1.9 \times 10^{-3}} = 4.88\text{k}\Omega$$

### **Indicators Design**

The Light Emitting Diode (LED) indicator chosen has  $100\Omega$  resistance and maximum voltage drop ( $V_{\text{drop max}}$ ) of 5V. The D.C indicator circuit shown in figure 6 is to be powered from a 12V D.C. source.



**Figure 6:** Indicator Circuit Diagram

Using voltage dividers rule and letting  $V_B$  be 9 V

$$\text{From } V_{R1} = \frac{V_{cc} \times R1}{R1 + R_D}$$

$$R1V_{cc} = V_R(R1 + R_D)$$

$$R1V_{cc} = V_R R1 + V_R R_D = R1V_{cc} - V_R R1 = V_R R_D$$

$$R1(V_{cc} - V_R) = V_R R_D$$

$$R1 = \frac{V_R R_D}{V_{cc} - V_R} = \frac{900 \times 100}{12 - 9} = \frac{900}{3} = 300\Omega$$

For  $V_{cc} = 10V$  and  $V_R = 8V$

$$R1 = \frac{V_R R_D}{V_{cc} - V_R} = \frac{8 \times 100}{10 - 8} = \frac{800}{2} = 400\Omega$$

The power supply circuit and the complete circuit diagram of the design are shown in figures 7 and 8 respectively.



## RESULTS AND DISCUSSION

Essentially, the design of the automatic temperature controlled switch was planned to work in three states, that is; ambient temperature below  $25^{\circ}\text{C}$ , normal temperature, at  $25^{\circ}\text{C}$ , and above  $25^{\circ}\text{C}$ . The design was implemented and tested with manual simulation of the thermistors using variable resistors designated  $RT1$  &  $RT2$ . The variable resistors are of equal resistance range with the thermistors. This is to provide testing alternative since the temperature variation with which the device was designed may not be obtainable in few months. When simulated for higher temperature, that is,  $RT1$  &  $RT2$  less than  $R1$  &  $R2$  while  $RV1$  &  $RV2$  are set to zero ohms ( $0\Omega$ ) the device automatically switches ON the air-conditioner to provide cooling effect and heater switched OFF. When simulated for lower temperature, that is  $RT1$  &  $RT2$  remaining in the previous position the heater was switched ON and air-conditioner OFF to provide warmth. On simulation for normal temperature ( $25^{\circ}\text{C}$ ), that is,  $RT1$  &  $RT2$  equal to  $R1$  &  $R2$  with  $RV1$  &  $RV2$  still zero ohms ( $0\Omega$ ) the device could not immediately switch OFF the air-conditioner and the heater as expected from the design calculations and scientific assumptions.

## CONCLUSION AND RECOMMENDATION

The focus of this design and its implementation is affordability, a requirement the design and implementation met. The design is simple to understand and very cheap to execute. However, the device could be improved upon for more sophistication either in the use of more sensitive component or the use of microcontroller.

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