Developing a Smart Blind System

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This report will cover the details and processes of designing a smart blind system, particularly at the circuit level where all circuits designed through the platform "National Instruments – Multisim", will be explained. The smart blind system was designed to be able to automatically close a window blind when there is too much sunlight. The system consisted of multiple subcircuits including a light sensor in a Wheatstone bridge, a conditioning circuit, comparator, full-wave rectifier and a final power amplification circuit. All subcircuits were integrated and simulated within Multisim and results will be illustrated within this report.

I. Introduction

Smart devices, like any other device, are made from a range of different components and they are a great example of new technology, however, the definition of "smart" in electronics is often mistaken. We do not need an advanced AI like Siri or Alexa, or a WIFI and Bluetooth connection to the phone. In fact, it can be relatively simple to build a smart device. This is what I will demonstrate in this report by designing the circuitry for a smart blind. Each section of the report will cover the design process for a sub-circuit that is part of the overall system. In these designs, I will consider the price and availability of components as well as circuit efficiency so that profit margins are maximized, much like if I was working for an electronics company.

The first section and starting point of the circuit is the light sensor in a Wheatstone bridge which has to be able to sense the illumination strength. This then connected to a conditioning circuit which was used to read and amplify the differential output voltage of the Wheatstone bridge. A comparator circuit was then designed to determine whether the illumination strength is above a set threshold which connected to and controlled a power amplifying circuit containing the motor, turning it on or off depending on the input, and therefore, the output voltage of the comparator. This power amplifying circuit had its voltage supply generated from a full-wave rectifier circuit, operating from a 240 V mains AC power supply. Each circuit will be explained in further detail in the following sections.

II. Light Sensor

The first sub-circuit in the system is the circuit containing the light detecting component. There are two different options for this component: A photodiode or a light dependent resistor (LDR). Both of these components operate similarly since their characteristics change according to the light intensity. However, they differ in their response to this change in light intensity, the photodiode responds with a change in current, whereas the LDR responds with a change in resistance. The photodiode could be considered better due to its extremely fast response time where the current changes very quickly in response to a change in light intensity (often in the range of nanoseconds), compared to the change in resistance for an LDR (usually in the range of seconds) [1]. This difference in response times is due to the different structures and operations of these devices. The photodiode is made from a p-n junction much like a regular diode except the casing is transparent and any light that hits the "active area", increases sensitivity. Optics are often used to focus light into this area and maximize current. Whereas the LDR is made from a semiconductor material whose conductivity changes according to light hitting its "active area". This is an advantage that the LDR has in that it is more durable than the photodiode, it is less prone to damage and is longer-lasting.

Both of these components would work well for this system but seeing as the response time between seconds and nanoseconds is not a crucial factor and a more important factor is the durability, I felt that the LDR is the better choice of component for this system. Unfortunately, Multisim, the software platform that the simulations took place in, did not have a photodiode model in its library. Instead, a voltage-controlled resistor was used to simulate an LDR where the voltage input simulated the light intensity.

Since I chose to use the LDR as the sensor, I needed to create a circuit that took a change in resistance and converted this into a change in voltage. There are multiple configurations to achieve this, for example, you can use a voltage divider to measure the voltage across the LDR which is shown in figure 1. For this circuit, the output voltage can be calculated using equation 1.

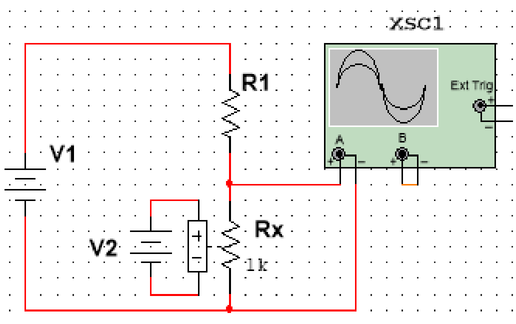

Fig. 1. Multisim screenshot of light sensor in Voltage Divider

$$V_{out} = V_1 \times \left(\frac{R_x}{R_1 + R_x}\right) \quad (1)$$

This method of resistance to voltage conversion is suitable for this system since resistance changes from the LDR sensor are relatively large compared to the resistance change from a strain gauge for example. However, a more accurate method for converting resistance changes to voltage changes is by using a Wheatstone bridge configuration, shown in figure 2. This allows measurements of changes down to the millionth range. It uses two series-parallel arrangements of resistances connected between a voltage supply terminal and ground while the points between each set of resistances, shown in figure 2 to be C and D can be used as the output voltage, where a change to any resistances leads to a change in voltage output.

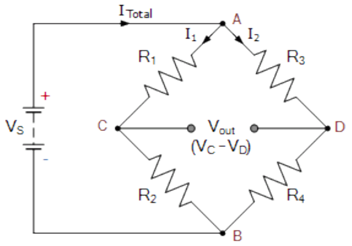

Fig. 2. Wheatstone bridge circuit diagram [2]

An important rule surrounding this configuration is that when the bridge is balanced, the voltage at point C is equal to that of point D. When this happens, no power is being drawn by the circuit, thus increasing its accuracy by alleviating the loading effect.

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} = 1 \tag{2}$$

If we set R_4 to a known resistance of an LDR R_x, and we know the three other resistance values, we can calculate the voltage output using equation 3.

$$V_{out} = V_{in}\left(\frac{R_2}{R_1 + R_2} - \frac{R_x}{R_3 + R_x}\right) \tag{3}$$

I wanted my simulations to be accurate, so I chose to model the voltage-controlled resistor of a real LDR. In this case, I chose the NORP12 model, a moderately cheap option for an LDR at £1.30 per product [3]. Since the blinds must close if there is too much light, the first step in designing this circuit is to determine what value is “too bright”. Light intensity is measured in lux, meaning lumens per square meter, and different light sources provide varying amounts of lux. For example, moonlight (essentially no light) provides a light intensity of approximately 0.1 lux whereas bright sunlight provides over 30,000 lux. Artificial light sources such as light bulbs fall somewhere in the middle of this scale with fluorescent light at around 500 lux [4]. Knowing these values, we can sensibly assume that any amount of light intensity above 1000 lux is “too bright” and we can design the blinds to close at this threshold.

The previously mentioned NORP12 LDR gives a resistance of 400 Ω in response to my threshold value of 1000 lux. Therefore, when the Wheatstone bridge circuit is balanced, the R_x resistance should be at 400 Ω as any voltage output below this means the resistance is too low and the light intensity is too high. This is illustrated in figure 3, showing the relationship between resistance and light intensity. Here you can see that resistance is inversely proportional to light intensity, which makes sense since the larger amount of light intensity hitting the semiconductor, the more conductive (or less resistive) the material is.

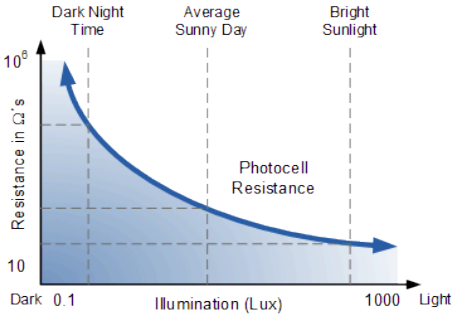

Fig. 3. LDR resistance vs light intensity [1]

Throughout this design, I used standard resistor values according to the E12 series as these are most commonly found and will help with the profitability of our system. These resistors are separated into 12 values in each “decade” meaning from 1 - 10 or 100 – 1000 for example [5]. The closest values to my desired 400 Ω were either 330 Ω or 470 Ω. Since we do not want the room to be too bright, it will be more advantageous to choose the higher value resistance so that less light is needed to pass the threshold. Therefore, the bridge was designed to give an output voltage of 0 V when R_x = 470Ω. I then chose permanent resistor values in the E12 series for the three additional resistors. These values are shown in the Multisim circuit in figure 4 alongside the input voltage which is 12 V (DC), designed according to the brief.

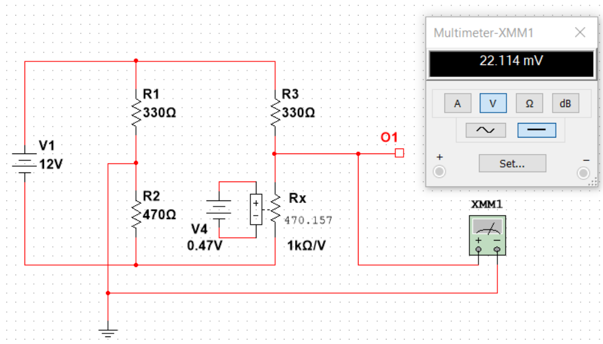

Fig. 4. Multisim screenshot of light sensor in Wheatstone bridge sub-circuit

When I run this simulation, the output voltage is 22.114 mV which is very close to the expected 0 V output and this difference is due to the inaccuracy of the voltage-controlled resistor with a resistance of 0.157 Ω higher than expected as you can see from figure 4. To check that this circuit is correct, and the output voltage should be 0 V, we can put the resistor values into equation 3.

$$V_{out} = 12\left(\frac{470}{330 + 470} - \frac{470}{330 + 470}\right)$$

$$V_{out} = 0 \text{ V}$$

When I decrease the resistance of R_x below 470 Ω, the output voltage is below zero meaning the blinds need to close whereas when the resistance of R_x is larger or equal to 470 Ω, the voltage is above zero, the light intensity levels are okay, and the blind can remain open. In the next circuit, I needed to find a method of shifting the voltage levels to input into a comparator.

III. Conditioning Circuit

The next sub-circuit to be designed for the smart blind system was a circuit to condition the output signal of the sensor circuit. This could involve noise reduction through filtering, linearization, impedance matching or signal level shifting. In this example, some of those factors are not necessary based on the signal from the Wheatstone bridge. No linearization is necessary since the output from the voltage-controlled resistor is linear, opposed to that of a photodiode with a nonlinear IV curve. The same applies to any noise reduction since there will be no noise associated with this simulation. However, it is worth noting that in the real world, there will be some noise associated with a light sensor, in particular, an LDR due to its slow response time. The only factor I needed to address in this circuit was signal level shifting since I needed to simplify the sensor signal for the comparator in the next circuit.

By observing figure 3, we know that the resistance varies from just above 10 Ω to around 10 MΩ at the lightest or darkest light levels. Using the voltage-controlled resistor in circuit 1, I changed R_x to these highest and lowest levels and observed the multimeter to find the maximum and minimum voltage output.

- When R_x = 15 Ω, V_{out} = -6.467 V ~ -6.5 V
- When R_x = 10 MΩ, V_{out} = 4.885 V ~ 5 V

This is somewhat counter-intuitive since a higher voltage output means it is darker, and a lower voltage, lighter. We can change this relationship to achieve more ideal voltage outputs using a signal level shifting circuit. In this circuit, we use a rail-to-rail operational amplifier and change the resistances and power supply to the rails to vary the output voltage levels. These output voltage levels are desired to be 0 V for a dark room and 5 V for a light room and we achieve this through the following calculations.

$$Input \ = \ 5\,V \ - \ (-6.5\,V) \ = \ 11.5\,V$$

$$Output \ = 0\,V \ - \ 5\,V = \ -5\,V$$

Calculate R_4 and R_5:

Gain, $A_v \ = \ \frac{-5\,V}{11.5\,V} \ = \ -0.43, \qquad \frac{R_5}{R_4} \ = \ -0.43$

$R_4 \ = \ 27\,k\Omega$

$R_5 \ = \ 0.43 \ \times \ 27k\Omega \ = \ 11.61\,k\Omega \ \approx \ 12\,k\Omega$

When V_{in} = 5 V, V_{out} = 0 V

Calculate R_6 and R_7:

$$V_{offset} \ = \ 5\,V \ \times \ \frac{12\,k\Omega}{12\,k\Omega + 27\,k\Omega} \ = \ 1.53\,V$$

$$V_{R_6} \ = \ 5\,V \ - \ 1.53\,V \ = \ 3.47\,V$$
$$V_{R_7} \ = \ 1.53\,V$$

$$\frac{R_6}{R_7} = \frac{V_{R_6}}{V_{R_7}} = \frac{3.47\,V}{1.53\,V} \ = \ 2.27$$

$R_6 \ = \ 22k\Omega\,, \qquad R_7 \ = \ \frac{22\,k\Omega}{2.27} \ = \ 9.69\,k\Omega \ \approx \ 10\,k\Omega$

These final resistor values are illustrated in the following Multisim circuit from figure 5.

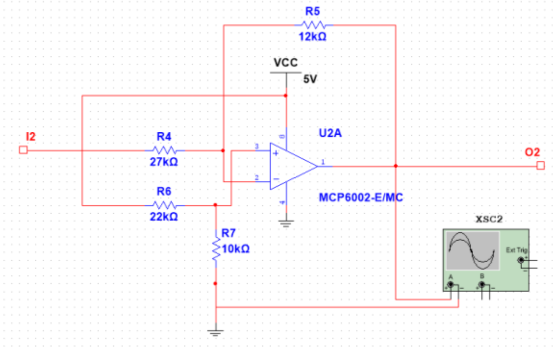

Fig. 5. Multisim screenshot of Conditioning Circuit

By observing my Multisim circuit, we can see all the resistor values previously calculated as well as the voltage levels for the operational amplifier rails, at 5 V and 0 V respectively. This makes the maximum voltage output (when it is light) at 5 V and the minimum voltage output (when it is dark) at 0 V. The voltage offset is the voltage going into the positive input of the operational amplifier and is an important value in shifting the voltage levels. The operational amplifier used in this circuit is the MCP6002 model and is a good choice for this circuit since it supports single supply voltage and is good for general-purpose circuits [6]. This model is also a good option from a business point of view due to its low price of £0.47 each [7].

After designing this circuit, when we run the simulation, we should get a voltage output of roughly 0 V from an input of around 5 V and a voltage output of roughly 5 V from an input of around -6.5 V. If the Wheatstone bridge is balanced and the voltage input is 0 V, the output should be roughly in the middle of 0 V and 5 V. The results are displayed on table 1 below.

TABLE I
Signal Level Shifting Input vs Output Voltage

Input Voltage (V)	Output Voltage (V)
-6.47	4.99
0.022	2.246
4.89	0.085

From table 1, we can see that the voltage amplification occurs as expected so that when it is darkest and the voltage is higher from the Wheatstone bridge, the voltage is converted to roughly 0 V. Additionally, the output voltage is converted to approximately 5 V when it is brightest and the voltage from the Wheatstone bridge is lower. The voltage output from the Wheatstone bridge has been amplified to a voltage range suitable for the next circuit through signal level shifting.

IV. Comparator Circuit

The next circuit to be designed is the comparator circuit, designed to provide a voltage output either high or low, depending on the voltage input levels. The first input is the signal from the previous conditioning circuit, the other is used to set a threshold voltage. This threshold voltage is a set value and if the voltage level at the other input exceeds this value, the output voltage will be equal to the voltage supplied to the upper rail. If the level is not exceeded, the output voltage is equal to the voltage supplied to the lower rail. The first step in the design should be to set this threshold voltage by making a voltage divider circuit, with equation 4 showing my calculations.

$$V_{threshold} = 5\,V \times \frac{10\,k\Omega}{10\,k\Omega + 12\,k\Omega} = 2.27\,V \qquad (4)$$

By adding two resistors to this comparator circuit, I made a voltage divider to set the threshold voltage, in this case, the threshold of my comparator circuit will be set at 2.27 V. I chose this value due to the output characteristics of both the light sensor circuit and the conditioning circuit where we saw that an output voltage of 0 V from the Wheatstone bridge means the output voltage of the conditioning circuit will be around 2.25 V. As was previously discussed, I centred my light sensor circuit to cross from a positive voltage to a negative voltage when it was determined to be “too bright”, and this threshold copies that principle as any value over 2.27 V will be “too bright”. The full circuit diagram for the comparator circuit can be seen below in figure 6.

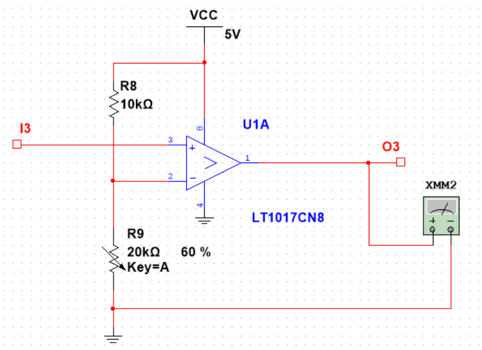

Fig. 6. Multisim screenshot of Comparator Circuit

While I calculated the necessary values for the resistors to give the desired threshold value, a practical design consideration may be to be able to change this threshold value, since consumers may have different opinions on what is “too bright”. For this reason, I placed a variable resistor of 20 kΩ in place of the 12 kΩ resistor from equation 4. When we adjust the variable resistor to 60%, this gives the desired value of 12 kΩ and a threshold voltage of 2.27 V. It can also be seen that the rails supply 5 V and 0 V respectively, therefore a voltage input bigger than the threshold should give an output of 5 V whereas an input smaller should give an output of 0 V.

When I ran this circuit, the voltage output was either 0.13 V for a room not too bright, or 3.18 V for when it is too bright. These values aren’t as accurate as predicted perhaps due to power loss within the comparator component. However, the circuit still works according to the brief and provides an output either high or low depending on if the room is too bright or at an okay level.

V. Full Wave Rectifier

In order to power the motor used to turn the blinds, we need a circuit providing a power supply much larger than the previous comparator circuit provides. This can be achieved by drawing power from the mains supply. However, the power from a mains supply is AC so we need to find a way to convert this into a DC supply for a DC motor. This can be achieved using a full-wave rectifier. A full-wave rectifier converts an AC signal to a DC signal through one of two methods, either using a centre-tapped transformer rectifier or using a bridge rectifier. Both methods flip the negative half of the AC waveform so that it is constantly oscillating within the positive region. In the case of my design, I chose to use the full-wave bridge rectifier. In this circuit, four diodes are used in a Wheatstone bridge configuration where a set of two diodes at a time allow current flow depending on whether the AC signal is in the positive or negative half-cycle. A transformer was used to step down the high AC voltage of 240 V from the mains. This can be seen in the circuit diagram shown in figure 7.

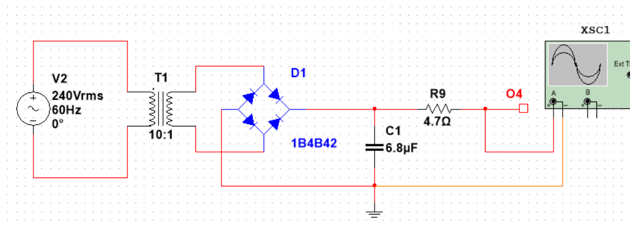

Fig. 7. Multisim screenshot of Full Wave Rectifier Circuit

As seen from figure 7, I also placed a resistor of 4.7 Ω which was used to reduce the current transferred to the next subcircuit, the power amplifier. Additionally, there is a capacitor of 6.8 µF which was used to reduce the ripple in the rectified AC voltage, making the final signal similar to a DC signal. The output signal of this circuit can be seen in the oscilloscope screenshot in figure 8.

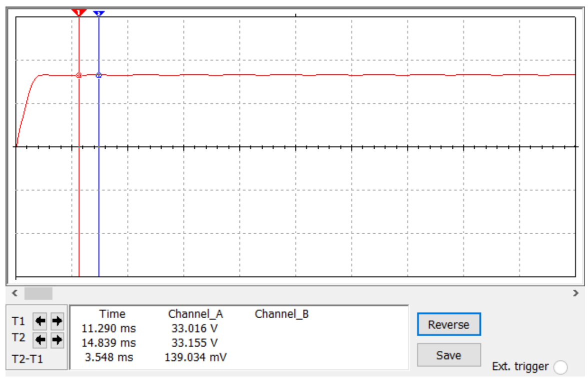

Fig. 8. Multisim screenshot of Oscilloscope for the full wave rectifier

Despite the output signal not being completely smooth due to the ripple, it will work well for the next sub-circuit since there is little variation in the voltage with the largest range being 0.139 V. Additionally, the sharp rise in voltage at the start of the waveform is from the charging period of the capacitor which will not affect the circuit. The 33 V generated in this circuit provides enough power needed to move the actuator in the next sub-circuit.

VI. Power Amplifier

The final sub-circuit of this smart blind system is the power amplifier, needed to supply enough current to the motor to turn the blinds. This circuit will draw power from both the full-wave rectifier and the comparator circuit in order to move the actuator by connecting both outputs from these circuits to a BJT transistor. The transistor I chose for this circuit was the 2N3055 NPN transistor, one which has a high DC current gain, β of 20 – 70, meaning the output current will be high compared to the input [8].

The bipolar transistor will allow a small current injected into the base, to control a much larger current flowing between two other terminals, the collector and emitter. In this design, the voltage output from the comparator will be fed into the base terminal while the voltage output from the full-wave rectifier will be fed into the collector terminal since the current from the comparator is much smaller than the current from the rectifier. When the voltage from the comparator circuit is low, meaning it is not "too bright" and the blinds can stay open, the voltage at the base terminal will be 0.113 volts. Any voltage below 0.7 volts at the base terminal is too low and the transistor will not operate, therefore whatever power supply is input into the collector terminal, there will be no current at the emitter terminal and therefore the motor will not run, and the blinds will not shut. The opposite is true for when it is "too bright" since the voltage from the comparator will be high and the base terminal voltage will be at 4.95 V. This voltage is large enough to allow current flow between the collector and emitter terminals, therefore the motor will receive enough current to be powered on. The diagram for this circuit is shown below in figure 9.

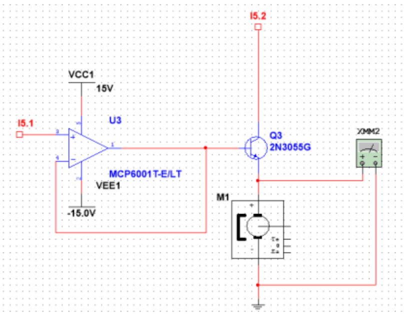

Fig. 9. Multisim screenshot of power amplifier circuit

As previously described, the circuit diagram includes the 2N3055 BJT transistor with the comparator output at I5.1 being wired to the base terminal while the full-wave rectifier output at I5.2 was wired to the collector terminal. In addition, an MCP6001 operational amplifier was used as a buffer circuit at the base terminal to reduce the extremely high impedance of the comparator signal. When I simulated the circuit under bright conditions with a comparator output voltage of 4.95 V, the voltage across the motor was 4.35 V with an associated current of 3.984 A, providing enough power to actuate the motor. On the other hand, starting the simulation under low light conditions with a comparator voltage of 0.113 V, gives a voltage across the motor of 2.391 μV, approximately 0 V. The current across the motor in this simulation was 2.4 nA, again approximately zero and far too low to power the motor.

The entire circuit when wired together is shown in figure 10 below.

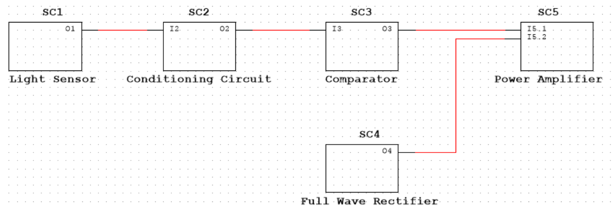

Fig. 10. Multisim screenshot of connected subcircuits

VII. Conclusion

The purpose of this experiment was to design a smart blind system, able to close the blinds if there is too much brightness in the room. This lab report, showcasing the five different sub-circuits of the complete system has proved that this task has been accomplished. The light sensor circuit was able to detect light and output a voltage depending on the light intensity while the conditioning circuit converted this voltage into a more suitable range for the comparator circuit. The comparator generated one of two voltage outputs, either high or low depending on light intensity which was fed to the final power amplifying circuit alongside a full-wave rectifier to power the motor on or off. The final voltage and current outputs proved that the motor will be on when the comparator voltage is high, or the motor will be turned off when the comparator voltage is low.

One way this experiment could be improved would be to use real electronic components rather than to simulate through Multisim. This way, the results may be more realistic since some components like the LDR were only simulated with a voltage-controlled resistor which may give less accurate results.

References

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