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A design perspective of an IR beam barrier and proximity detector

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Abstract: An inexpensive infrared beam barrier and proximity detector has been designed and analyzed using solid state discrete components. The result showed that a security system using infrared technology is possible and viable where the breaking of an infrared signal by objects including humans passing or wandering within restricted premises can be effectively monitored. The design was achieved with the help of IR Module and LEDs, a 555IC timer which oscillates at about 38kHz, a regulating IC which regulates a 9V dc to 5V, transistors, and variable resistors that contribute to the strength of the IR signal generated together with some other passive components. The completed device designed only requires an external power supply when the relay is to be used in triggering an external alarm or switching of bulbs. The design results also showed that the 555IC timer can be used to produce accurate timing ranging from microseconds to hours if the variable resistors can be reduced while the capacitors across it is increased. More so, it was evident from this study that the infrared which has a very small wavelength in micrometers as recorded in the electromagnetic spectrum, can be optimized to travel farther distances of over 250cm.

1. Introduction

The advent of modern technology has posed numerous challenges to human life in areas of security, cost, comfort and portability. The frontline issue amongst others have always been security and convenience, which cannot be over – emphasized. The quest for security has grown so enormous that trust among humans seems to be fading away by the tick of the clock. Security in the context of electronics cannot do without optics (light), including the least military personnel who use their eyes as an optical medium for visualization. Though, security has different dimensions in psychology, defense matters, etc, but in English, security has been defined as the state or feeling of being safe and protected (Microsoft Encarta dictionary, 2009). The infrared (IR) as a class of light and radiation as depicted from the electromagnetic spectrum has been employed in this research to automate security at some level of object passage and proximity detection by using an IR LED connected to a 555IC on a transmitter circuit on one hand and a Sharp model of an IR Module connected to a transistor and a relay for switching on a receiver circuit on the other hand.

The design of this art is arranged in such a way that the IR LEDs transmits a signal beam onto the IR Module that are both powered by a 9V dc source, so when an object obstructs the beam from the receiver, it causes the relay to trigger, which then activates an output signal and deactivates the same generated signal when the object is out of sight or range from the receiver. This is to imply that the object no longer obstructs the beam constantly generated from the transmitter onto the receiver. The focus of this design is to be able to detect objects passage within a range, which can effectively function within 250cm depending on the strength of the IR Module and the battery power on the transmitter in generating the IR beam signal. The motivation for this research is to design a miniaturized device for the detection of intrusion of unauthorized access to a confined zone or storehouse and to forecast a new definition for infrared transmission, which might require a dedicated administrator to a computerized monitoring system where such broken signals can be perceived from centralized security department or agency like the police. To limit the burden of this work, a buzzer and a light indicator LED has been added to the relay in order to enable us easily observe and hear a louder buzz than that of the relay itself.

2. A brief literature

The first experimental observation of invisible radiation (i.e. infrared radiation) beyond the red end of the Solar spectrum is credited to Sir Williams Herschel, Astronomer Royal to the King of England in 1800 and in 1940, photo detectors were developed to improve sensitivity and response time which led to Lead Sulphide (PbS) as the first practical infrared detector that was sensitive to infrared wavelengths up to ~3µm. The distribution of energy as a function of the wavelength from a blackbody at any temperature has been the subject of study by a number of leading scientists in the later part of the 19^{th} Century and the beginning part of the 20^{th} Century after the observation of Sir Williams Herschel in 1800. Laws such as Rayleigh Jeans, Wien Displacement Law and Planck's Law are all well – known landmarks in physics covering this area of infrared detectors' technology.

It could be evidenced that a monochromatic radiation propagating through the atmosphere has its radiance attenuated exponentially (Bouguer – Lamber – Law) where the attenuation could be due to absorption or scattering which can be expressed as;

$L_\lambda(x) = L_\lambda(0)\exp\{-[\alpha_a(\lambda) + \alpha_s(\lambda)]\} \ldots\ldots 2.1$

such that $\alpha_a(\lambda) and\ \alpha_s(\lambda)$ are respectively the spectral absorption and scattering coefficients at wavelength λ and these two can be combined into;

$$\alpha_T(x) = \alpha_a(\lambda) + \alpha_s(\lambda) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\Longrightarrow \alpha_T(x) = the\ extinction\ coefficient$$

From the Planck's law, we can determine the intensity of an infrared if the wavelength and temperature were known. By definition, the Planck's law is given as;

$$I(\lambda, T) = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{KT\lambda}} - 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where I is the intensity of the corresponding wavelength at a given temperature and K is them Boltzmann constant, but by transposing the above equation, we get;

$$\lambda = -\frac{1}{KT}\ln\left[\frac{hc}{\lambda^5 I(\lambda, T)}\right] \dots\dots\dots\dots\dots\dots\dots\dots\dots.\dots(3)$$

The infrared technology has virtually spanned through many applications in the years past for which this project design is of great interest. This project design is basically for the detection of barriers and proximity but it could also be used in the oil and gas sector where we have the capacitive and inductive sensors. An optical proximity sensor package has been developed and published in 2010 by the United States Patent that comprises an infrared light emitter and detector. The emitter is connected to and driven by a light emitter driving circuit and the detector connected to and driven by a detector sensing circuit. Optically transmissive infrared light pass components are used to cover the light emitter and detector and an optically non – transmissive infrared light barrier component is placed between the emitter and detector components where light reflected from an object in proximity to the sensor passes through the detector component and the infrared light barrier component substantially attenuates or blocks the transmission of undesired direct, scattered or reflected light between the emitter and detector, which results to minimizing of optical crosstalk and interferences between both the emitter and detector.

Examples of these devices are the AVAGO TECHNOLOGIES^{TM} HSDL-9100 surface mount proximity sensor, the AVAGO TECHNOLOGIES^{TM} APDS-9800 integrated ambient light and proximity sensor, etc. A proximity detector has also been created in 2005 which works on body capacitance and requires an essential earth grounded for proper operation and best sensitivity. (www.telus.net/chemelec/projects/projects.htm). Another invention of this type is the capacitive proximity sensor (similar to inductive proximity sensor) by Siemens. This sensor produces an electrostatic field instead of an electromagnetic field as in the case of the inductive proximity sensor. The capacitive proximity switches are capable of sensing metals as well as non – metallic materials such as paper, glass, liquids (including petroleum) and cloth. Another useful invention of infrared technology is the sensing techniques of mobile interactivity and GPS, which also involves special features like changing orientation, positions and venues. (Symposium on User Interface Software and Technology, Chi letters 2(2), pp. 91 – 100).

3. Materials and methodology of study

Amongst other components employed for this design, below are a brief description of the key components that greatly influenced the realization of the design and its functioning.

3.1 The 555IC timer (NE555):

This is a very popular general purpose timer. It can be connected as a free – running oscillator just as it has been used at the receiver circuit of this work or as a one – shot as equivalently used at the transmitter circuit. The output of this oscillator is a repetitive rectangular waveform as shown below in figure 1 and figure 2 showing how the external components can be connected to this timer in order to enable it operate as a free – running oscillator.

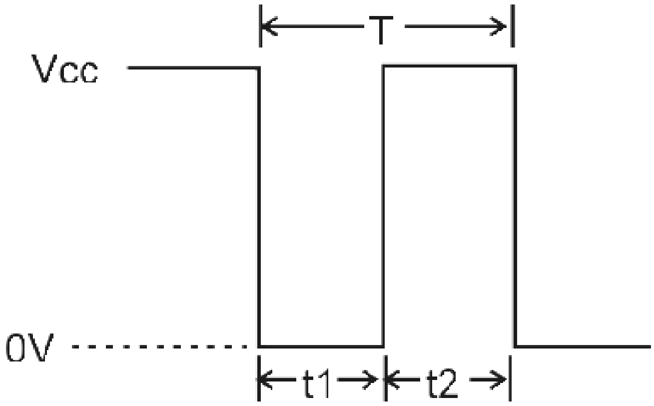


Figure 1: Switching time of 555IC timer

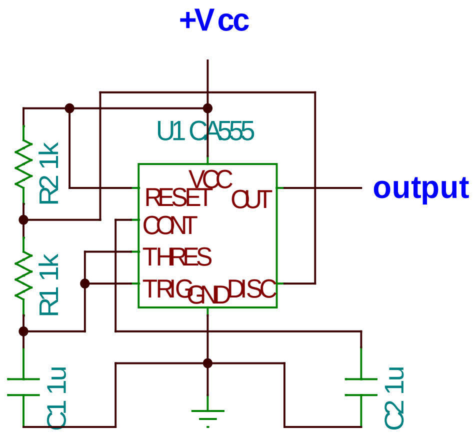


Figure 2: A typical 555IC timer and its connection to other components

As seen from the diagram above, the output switches between two logic levels with the time intervals (t_1 and t_2) at each level. These time intervals are determined by R and C values. t_1 is given by $0.7R_BC$ and t_2 is equal to $0.7(R_A + R_B)C$. Therefore, the time period T of the output waveform is:

$T = t_1 + t_2$ ………………………… (4)

and the frequency (f) is:

$$f = \frac{1}{T} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

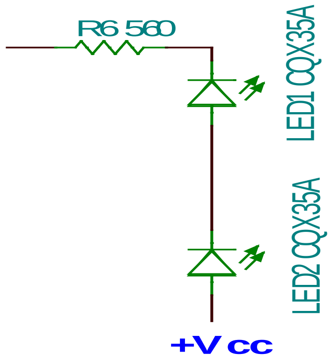
To get the duty cycle of the waveform, we have that:

$$Duty\ cycle = \frac{t_2}{T}\ x\ 100\% \ldots\ldots\ldots (6)$$

It is worthy to note as a design guide from the above that t_1 can never be equal to t_2 unless R_A is equal to zero. If this is done, an excess current will flow through the device, which could be disastrous. The time at which the output is HIGH is given by $t_2 = 1.10R_AC$. The oscillation of the timer serves to regulate both the intensity of the IR LEDs and the time response of the receiver. To maintain focus of the aim of this work, the timer has been configured to oscillate at about 38kHz using the standard 10kΩ.

3.2 The IR LED and Module:

The IR LED is responsible for the IR signal being generated whereas the IR Module picks this generated signal up at the receiver circuit. The IR Module uses the Sharp type, but the Vishay type can also be used for this purpose. The duty cycle of the IR beam is about 10%, this allows more current through the LED, which in turn allows a greater range of transmission as applicable in real



life like the TV and car key remotes. This implies that the current from the source is proportional to the intensity of the IR beam.

Figure 3a: IR LEDs connected to other components

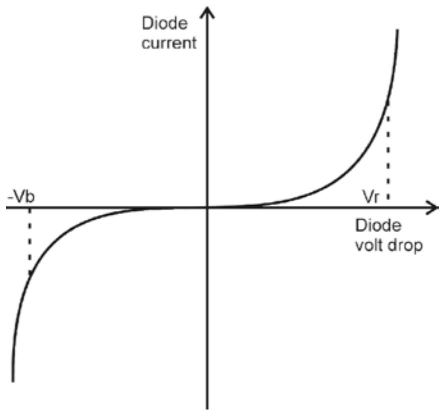


Figure 3b: forward and reverse biased diode curve characteristics

3.3 The transistors (BD140 and BC547):

The transistors used in this design are two, of type BD140 and BC547. The major work of the transistor is to control the level of current that passes onto the 555IC timer, which determines the response time or duty cycle at which the alarm turns ON or OFF.

3.3.1 Equations involving basic transistor operation:

When $I_C = 0$ it implies that $V_{CE} = V_{CC}$. Ideally, I_C cannot be equal to zero since a little leakage amount of I_{CEO} always flows even when the transistor is OFF. (Mehta, et – al 2005), hence,

$V_{CE} = V_{CC} - I_{CEO}R_C$ ……………………(7)

where V_{CE} is the output current and R_C the collector resistance.

Power loss (P_L) = V_{CC} x I_{CEO} …………..(8)

When the transistor is in its ON state, the saturation collector current $I_{C(sat)}$ which is the maximum collector current I_C for a particular load in a transistor is given as:

$$I_{CE(sat)} = \frac{V_{CC}}{R_C} \text{ and } V_{CE} = 0,$$

$$where\ V_{CE} = V_{CC} - I_C R_C \dots\dots\dots\dots\dots (9)$$

Though under ideal situations, V_{CE} cannot be zero as well

$$\Rightarrow I_{C(sat)} = \frac{V_{CC} - V_{CE}}{R_C} \dots\dots\dots\dots\dots\dots (10)$$

$$\therefore Power\ loss\ (P_L) = V_{CE} - I_{C(sat)} \dots\dots\dots (11)$$

$$also;\ I_\beta = \frac{I_{C(sat)}}{\beta_{dc}}$$

To ensure effective oscillations, the transistor must saturate for which minimum values of β_{dc} *are as thus;*

$$\beta_{dc(1)} = \frac{R_1}{R_{L1}} \text{ and } \beta_{dc(2)} = \frac{R_2}{R_{L2}} \dots\dots (12)$$

If $R_1 = R_2 = R$ and $R_{L1} = R_{L2} = R_L$ then $\beta_{dc(min.)} = \frac{R}{R_L} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (13)$

and

$T = T_1 + T_2 = 0.69(R_1C_1 + R_2C_2)$ …….(14)

where $T_1 = 0.69R_1C_1$ and $T_2 = 0.69R_2C_2$

also when $R_1 = R_2 = R$ and $C_1 = C_2 = C$, we get $T = 1.38RC$ ………………………….(15)

3.4 The relay:

The relay is basically used to trigger an external alarm system or for switching of bulbs in homes. This role of the relay should be noted that, it depends on the amount of current that is passed onto the timer IC that is responsible for its activation or deactivation.

3.5 The regulator IC:

The regulating IC is capable of regulating the voltage supply used in powering the receiver circuit. It actually receives a minimum of 8V dc and regulates it to about 5V, which is its input voltage. For an equivalent resistance R for R_A and R_B at 30900Ω, the oscillating frequency was found to be $0.001\mu F$. this is shown below:

$$f = \frac{1}{T} = \frac{1}{1.38RC}$$

$$\Rightarrow C = \frac{1}{1.38fR} = 0.001\mu F \dots\dots\dots\dots (16)$$

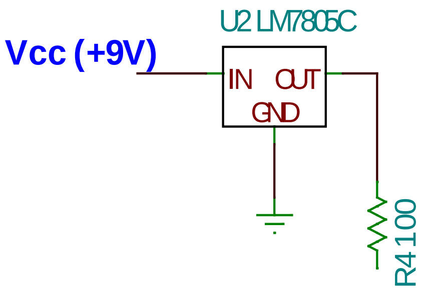


Figure 4: The Regulator IC as it connects to other components

3.6 Methodology:

An infrared beam barrier and proximity detector was designed with an IR LEDs and IR Module alongside a relay, regulator IC, 9V battery, 555IC timer, a buzzer, and passive components to detect the passage of objects between a transmitter and a receiver and also capable of detecting objects within a proximity range of about 250cm. The system was designed and categorized into two key components: The Transmitter and the Receiver.

3.6.1 The transmitter:

The components that make up the transmitter are the 555IC timer, the IR LEDs, the variable resistor which enables the regulation of the intensity of the IR signal from the LEDs through the 555IC timer. The 9V battery was also a key component in regulating this intensity to achieve greater distance of transmission and the manufacturer's datasheet of the timer and IR LEDs were also consulted in depth to ease the determination of the matching values for the transmitter.

From the datasheet of NE555, we were able to determine the total time response of the input voltage at an oscillating frequency of 38kHz (i.e. $F_{(osc)}$ = 38kHz) to be;

$$T = \frac{\frac{2}{3}V_{CC}R_E(R_1 + R_2)C}{R_1V_{CC} - V_{BE}(R_1 + R_2)}V_{BE} \dots\dots\dots\dots (17)$$

where the rise and fall time of the output (t_r and t_f) is 100ns respectively and t_{off} (turn off time at $V_{reset} = V_{CC}$) is 26µs.

Similarly, the key resistors on this component (R_5/R_A and R_7/R_B) have been evaluated as shown below:

$$R_A = \frac{V_{CC} - V_{reset}}{I_{reset}}$$

$$= \frac{9 - 0.7}{0.31} = 27k\Omega\ (approx.) \dots\dots\dots. \dots (18)$$

$$R_B = \frac{V_{th} - V_{trig}}{I_{tt}}$$

$$= \frac{6 - 3}{0.78} = 3.9k\Omega\ (approx.) \dots\dots\dots\dots\dots.. (19)$$

where $I_{tt} = I_{trig} + I_{thres}$

3.6.2 The Receiver:

Again, on the receiver component are the 555IC timer as discussed above, the BD140 and BC547 transistors, the regulator IC and the IR Module. The key function of the receiver is to be able to receive the IR beam emanating from the transmitter unto the IR Module and also capable of regulating an 8V dc or more to about 5V as its input capacity through a regulator IC which has all been configured to suit the objective of the system.

4. Result and Discussion

Below is the result of the various components put up to achieve the system with two distinct circuits (the transmitter and the receiver).

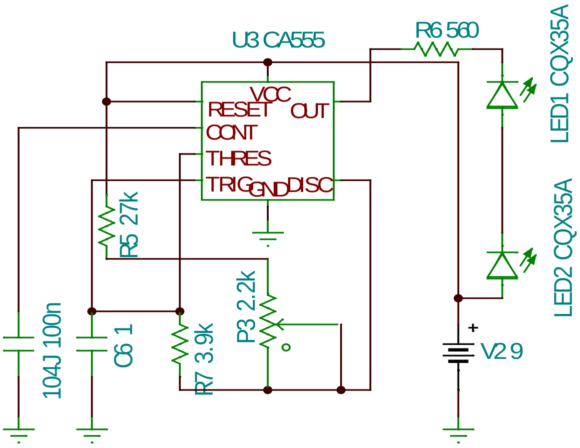


Figure 5: completed IR Transmitter circuit

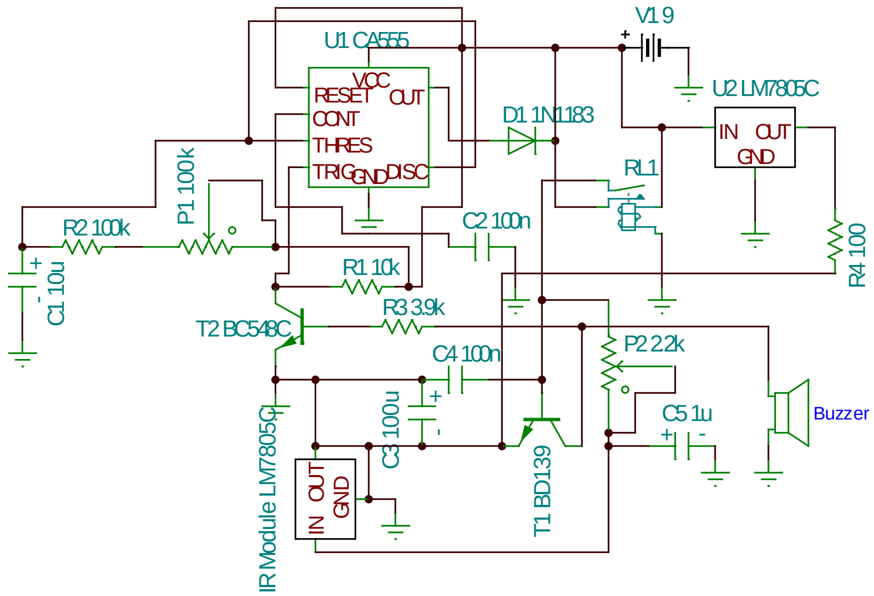


Figure 6: completed IR Receiver circuit

4.1 Discussion

The system designed is a complete combination of a 555IC timer, IR LEDs and IR module, two transistors (BC547 and BD140), and a relay capable of detecting passing objects using a battery of 9V on each circuit that is regulated to 5V. The timer IC from the transmitter circuit determines the intensity of the IR LEDs beam through the 2.2kΩ variable resistor that sets the current which goes through the timer and the frequency of oscillation to 38kHz. Similarly, from the receiver circuit, the variable resistor 2.2kΩ is set to trigger the timer IC through the BC547 transistor, where any excess current is reset by the 27kΩ resistor after being drained to earth and the regulator IC only sends +5V into the circuit from the supply voltage of 9V. The relay can also be used to trigger an external alarm system or switching of bulbs. The Boltzmann diode equations can also be used to determine the diode reverse saturation current thus;

$$I = I_o\left(e^{\frac{eV}{kT}} - 1\right) ampere \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

where I is the total supply current, I_o is the reverse saturation current, V is the voltage across the junction, k is the Boltzmann constant ($1.38 \times 10^{-23} J/^oK$) and T is the crystal temperature in k. Furthermore, the energy generated by the system can be found from the relation

$$E = \frac{IA}{(2l)^2} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. \ldots \ldots \ldots .. \ldots . (21)$$

where A is the area of the sensor, I is the intensity, ℓ is the distance travelled and E is the energy and the distance travelled is also represented in terms of the sensor's radius and angle of radiation as:

$$l = \frac{d}{cos(\alpha)} + r\left[\frac{1}{\cos(\alpha)} - 1\right] \ldots \ldots \ldots \ldots \ldots (22)$$

and

$$E = \frac{C_o \cos(\alpha) + C_1 \cos(2\alpha)}{\left\{\frac{d}{\cos(\alpha)} + r\left[\frac{1}{\cos(\alpha)} - 1\right]\right\}^2} \ldots . \ldots \ldots .. (23)$$

such that C_o and C_1 are constants, r is the radius of the sensor, d is the known distance of the sensor position, α is the angle of emission and 2α is the angle of reflection.

5. Conclusion and Recommendation

This design was carried out with the aim of achieving a portable device that can monitor the passage of objects and proximity detection within a restricted area and reducing the complexity and cost of installing surveillance/CCTV cameras as the parts were very cheap and easy to design. The cost effectiveness was reduced and the passage of objects and their proximity were ably monitored. The frequency of oscillation was not varied and the IR LEDs were not shielded and so there were slight erratic response from the system to proximity of objects, but the breaking of the IR beam when objects passes between the transmitter and the receiver within a range of 100cm to 250cm was effectively detected.

5.1 Recommendation

The system designed works very well at dark premises where there are no remote or day light interferences and it was very cheap to design. Interested designers should pay more attention to increasing the power source to enable the unit radiate farther, and shield the IR LEDs properly to avoid erratic responses on the proximity detection.

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