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Study of Illumination in LDR with Power Variation

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Abstract : Light-dependent resistors, commonly known as LDR sensors, have revolutionized the way we interact with light in various electronic applications. These simple yet powerful components have an influence on numerous devices you encounter in your daily life. LDR sensors work on the principle of photoconductivity, changing their resistance based on the intensity of light they're exposed to. This unique property makes them invaluable in applications ranging from street lighting systems to camera exposure controls.

In this project, well discover the illumination response of light dependent resistors (LDRs) under varying power condition to analyze their behavior, inner workings of LDR sensors and explore their diverse applications. We'll break down the LDR working principle, delve into different types of LDR sensors, and examine their sensitivity to various wavelengths of light. Experimental data were collected using a controlled setup involving adjustable light sources, LDR sensors, and measurement circuits to record voltage and resistance variations. We'll also learn about common LDR circuits and how these sensors are put into action in real-world scenarios.

By the end, we'll have a solid understanding of why LDR sensors continue to be a go-to choice for light detection in many electronic design.

I. Introduction:

LDR (Light Dependent Resistor) as the name states is a special type of resistor that works on the photoconductivity principle means that resistance changes according to the intensity of light. Its resistance decreases with an increase in the intensity of light.

It is often used as a light sensor, light meter, Automatic street light, and in areas where we need to have light sensitivity. LDR is also known as a Light Sensor. LDR are usually available in 5mm, 8mm, 12mm, and 25mm dimensions.

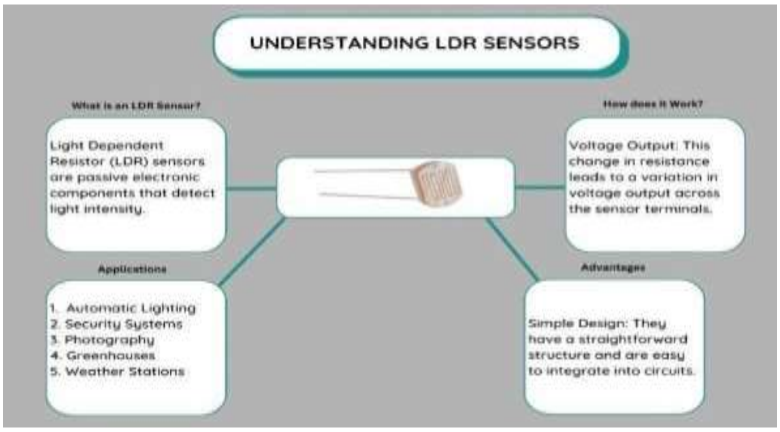


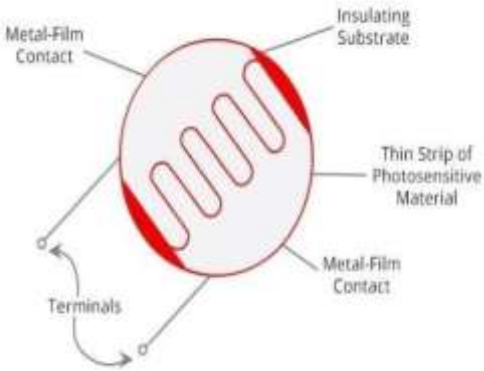
Figure 1: Understanding LDR Sensors

A Light Dependent Resistor (LDR) is a type of passive electronic sensor used to detect light. It's made up of two conductors separated by an insulator which becomes more conducting when exposed to high levels of light intensity, forming a variable resistor in the circuit. This allows it to measure the amount and brightness or darkness within its environment and provide information accordingly.

LDR light sensors are typically used as automated lighting control systems for conservation purposes such as dimming lights based on natural daylight that can be detected outside without human intervention.

Furthermore, they have found the application of LDR sensor in motion detectors like burglar alarm security systems because they can tell if something passes through their beam line quickly enough from dark-to-light conditions created with most forms of ambient lighting sources present today such as LED, etc., making them ideal sensing tools both commercially C domestic level settings alike.

Definition of LDR: An LDR is a special type of resistor that works on the photoconductivity principle means that resistance changes according to the intensity of light. An optoelectronic sensor that's used for detecting light in the environment. This remarkable device plays a crucial role in various applications by changing its electrical resistance based on the intensity of light it's exposed to.



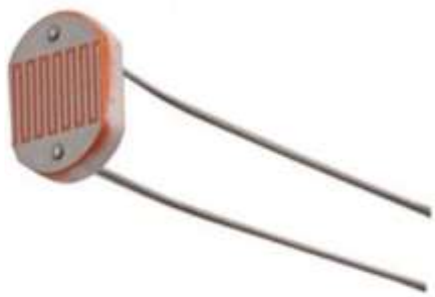


Fig 2.a LDR (Structure) **Fig 2.b (Exterior)**

A LDR also a photocell, or photo-conductive cell, is a light sensitive resistor or a light- sensitive sensor used in electronic circuit designs for the purpose of detecting the presence or intensity of light. The resistance values of LDRs can vary across multiple orders of magnitude, with resistance decreasing as the light level increases. That is, it exhibits a change in resistance when exposed to light.

Terminology:

- The term “light-dependent resistor” (LDR) is a descriptive name based on the component’s core function: it is a resistor whose resistance changes in response to light.
- The terms: “light” referring to the environmental stimulus, “dependent” indicating a relationship between resistance and light, and “resistor” identifying the component’s primary functions.
- This makes it an essential tool in many automation systems because it helps detect objects without any physical contact with them.
- In addition to this, they have low power requirements making them ideal for energy-saving applications like solar cells and garden lighting systems where their high sensitivity allows precise illumination control even under tightly controlled conditions.
- Their small size further increases flexibility as well giving these devices versatility across multiple different projects while still being able to fit inside tight spaces too.
- Most home appliances, outdoor lighting, and streetlights are normally operated and maintained manually.
- This is not only dangerous, but it also wastes energy due to staff negligence or unforeseeable events when turning this electrical equipment ON and OFF.
- Therefore, by using a light sensor, we can Automatically shut off the loads based on the Intensity of the daylight.
- The LDR light sensor is a passive component that produces an electrical signal from this “light energy,” whether it is in the visible or infrared portions of the spectrum. Because they transform light energy (photons) into electricity, light sensors are more generally referred to as “Photoelectric Devices” or “Photo Sensors” (electrons).

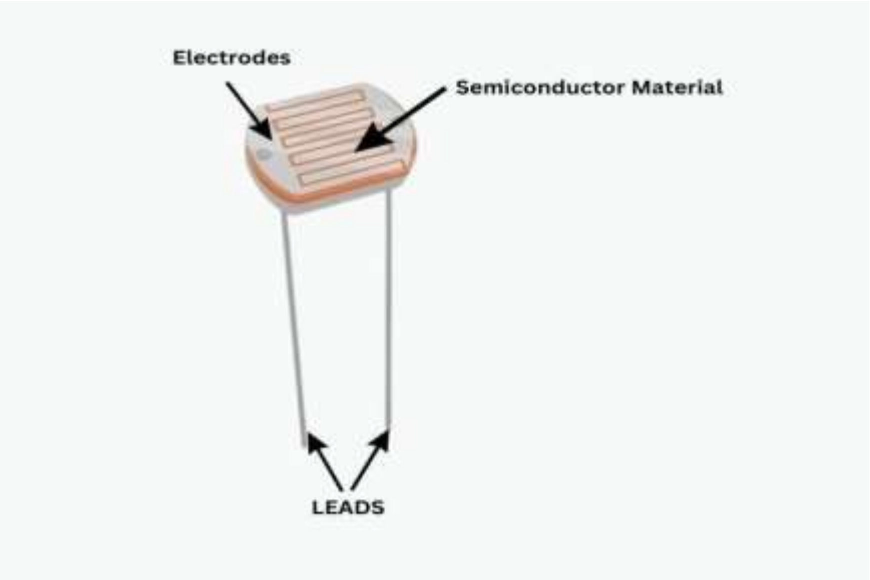


Fig 3. LDR

- It can be divided into two primary categories: photovoltaics and photo-emissions and photo-resistors and photo-conductors, which modify their electrical properties.
- LDR light sensor is also referred to as a photo resistor, photocell, or photoconductor. It is a specific kind of resistor, and the amount of light that strikes its surface affects how much resistance it exhibits.
- A light-dependent resistor or LDR is an example of an electrical component that responds to light. When light beams strike it, the resistance changes right away. An LDR’s resistance levels can vary by several orders of magnitude. As the light level rises, the resistance value will decrease. LDR resistance values range from many mega Ωs in complete darkness to only a few hundred Ωs in strong light. As a result these resistors are used in variety of applications due to this variation in resistance. The wavelength of the incident light affects the LDR sensitivity as well.

- Light Dependent Resistor (LDR) technology is widely used in many industrial, educational, and commercial applications. Its highly sensitive contactless operation allows it to replace mechanical switches for a wide range of needs.
- The LDR sensor works as a light sensor or solar radiation detector, controlling street lights on highways, automatically changing the direction of traffic signals at intersections, and even photoelectric equipment such as smoke detector alarms all rely upon this small but efficient device which monitors changes from darkness into ambient light with impressive accuracy.
- LDR works extensively to monitor temperatures inside refrigerators C freezers while keeping an eye out for heat/cool fluctuations that could cause food spoilage – ensuring optimal performance every single day.

Components description:

1. **TRANSISTOR:** When a thin slice of p-type is sandwiched Between two blocks of n-type, then n-p-n transistor is formed. It consists of emitter, base, and collector. In the project, common emitter n-p-n transistor (BC-147 C SL-100) is used.
2. **DIODE:** When a p-type and n-type semiconductors are joined a diode is formed. It conducts when forward biased and does not conduct when reverse. Biased. In the project, IN-4007 diode is used.
3. **RELAY:** It helps to contact and dis contact. In the project, we use relay of 6 Ωs.
4. **CARBON RESISTOR**: A carbon resistor has generally four rings or bands A,B,C and D of different colour corresponding to the value of resistance. In project, we use carbon resistance of 220 kiloΩs, 1.5 kilo-Ωs and 820 Ωs.
5. **LDR: L**DR means light dependent resistance which is used to complete the circuit.
6. **TRANSFORMER: T**ransformer is used to convert low alternating voltage to high alternating voltage by decreasing the current and vice versa. We use a transformer of 0 to 6 V for the circuit.
7. **CAPACITOR:** Capacitor is used to block DC. In the circuit, we use the capacitor of 220mfd and 1000mfd.
8. **BULB:** An electric bulb is connected to the circuit when LDR comes in the darkness.

PHOTORESISTOR: A photoresistor (or light- dependent resistor, LDR, or photocell) is a light-controlled variable resistor. The resistance of a photoresistor decreases with increasing incident light intensity; in other words, exhibits photoconductivity. A photoresistor can be applied in light-sensitive detector circuits, and light- and dark- activated switching circuits. A photoresistor is made of a high resistance semiconductor.

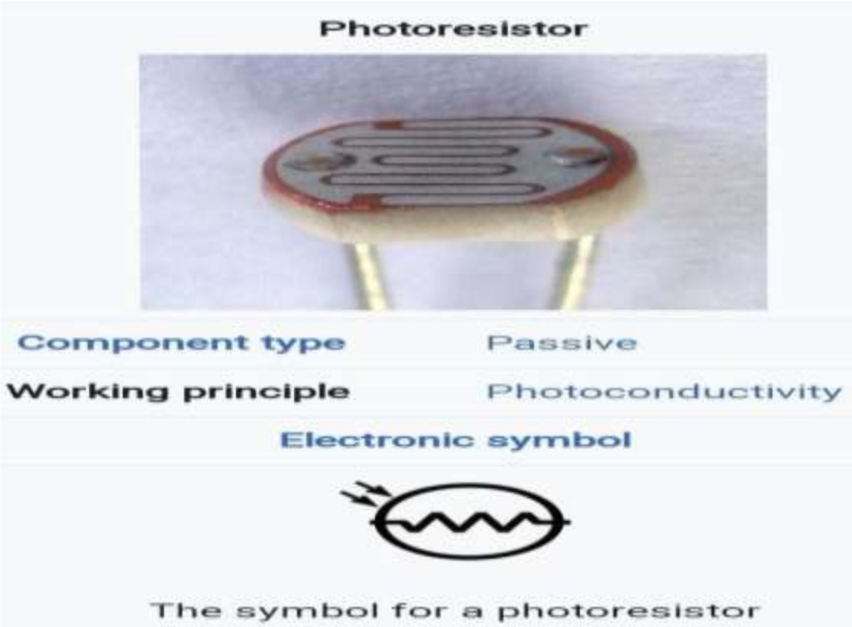


Figure 4. Photoresistor

In the dark, a photoresistor can have a resistance as high as several megΩs (MΩ), while in the light, a photoresistor can have a resistance as low as a few hundred Ωs. If incident light on a photoresistor exceeds a Certain frequency, photons absorbed by the semiconductor give Bound electrons enough energy to jump into the conduction band. The resulting free electrons (and their hole partners) conduct electricity, thereby lowering resistance.

II. Background Details

Discovery of LDR: The LDR, dates back to the 19^{th} century when the phenomenon of photoconductivity was first discovered. In 1873, British engineer Willoughby Smith made a groundbreaking observation while working on underwater telegraph cables. He was testing selenium as a material for improving the quality of the cables and unexpectedly found that its electrical resistance decreased when exposed to light. This was the first recorded discovery of photoconductivity—the property where a material becomes more conductive in the presence of light.

Following this discovery, in 1876, scientists William Grylls Adams and Richard Evans Day conducted further experiments on selenium. They confirmed Smith's observation and established that light could generate an electric current in selenium, marking an early step toward the development of modern photoelectric devices.

In the early 20^{th} century, particularly T.W. case in 1920, led to the development of various photocells, including the "Thalofide Cell". Subsequent research in the 1930s and 1940s, including studies of PbS, PbSe, and PbTe, and the development of photoconductors from silicon and germanium, further refined the technology.

In the mid-20^{th} century, the development of practical LDRs became possible with the use of new materials such as cadmium sulfide (CdS) and cadmium selenide (CdSe). These materials were found to offer a strong, stable, and repeatable photoconductive response to visible light. This made them ideal for mass production in electronic components, and LDRs became widely available in the 1950s and 1960s.

Structure of LDR: The photoresistor is a light-sensitive resistor that has a flat, horizontal body which is exposed to light. The lightly doped active semiconductor region is deposited onto a semi-insulating substrate and this arrangement ensures the light-sensitivity of the photoresistor.

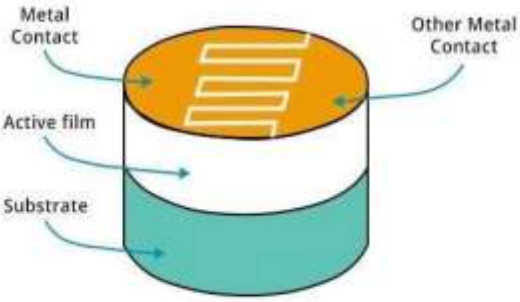


Figure 5. Structure of LDR

In many discrete photoresistor devices, an interdigital pattern is employed to enhance the area of the photoresistor that is exposed to light. This pattern is etched into the metallization layer on the surface of the active region, allowing light to pass through. The two metallized areas serve as the contacts for the resistor. It is essential for this area to be relatively large to minimize the resistance at the contact points with the active region.

Semiconductor materials used for constructing photoresistor include CdSe, CdS, CdTe, InSb, InP, PbS, PbSe, Ge, Is, and GaAs. Each material offers distinct properties in terms of wavelength sensitivity and other factors.

Working Principle of Light Dependent Resistor: LDRs operate based on the principle of photoconductivity. The principle of photoconductivity states that certain materials, known as photoconductors, exhibit changes in their electrical conductivity when exposed to light.

In the case of an LDR, which is a photoconductive material, when light falls on it, the energy carried by the light is absorbed by the material. As a result, the electrons in the valence band of the photoconductive material become excited and go to the conduction band. This process leads to an increase in conductivity proportional to the intensity

of the incident light.
For this phenomenon to occur, the energy carried by the incident light must be greater than the bandgap energy of the photoconductive material. Only then can the electrons in the valence band be excited to the conduction band.

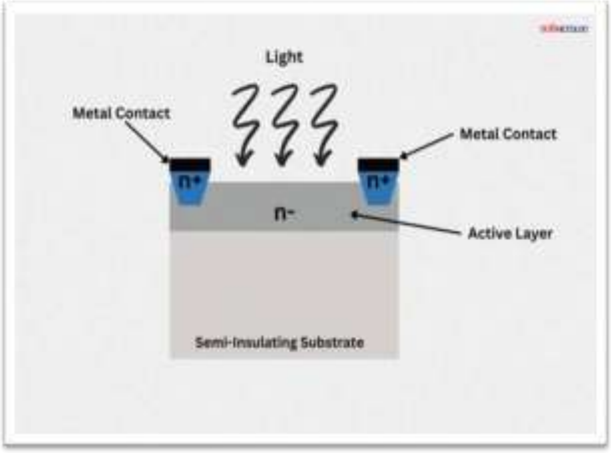


Figure 6. Working Principle of Light Dependent Resistor

In its unilluminated state, a LDR exhibits the highest resistance, however, as light intensity increases, the resistance of the LDR decreases accordingly.

Mechanism:

- A photo resistor or photocell is a component that uses a photo conductor between two contacts. When this is exposed to light a change in resistance is noted.
- Photo conductivity the mechanism behind the photo resistor results from the generation of mobile carriers when photons are absorbed by the semiconductor material used for the photo conductor.
- While the different types of material used for light dependent resistors are semiconductors, when used as a photo-resistor, they are used only as a resistive element and there are no PN junctions. Accordingly the device is purely passive.

Variations in resistance to change in intensity: An electrical current is characterized by the movement of electrons within a material. Materials with high conductivity possess a large number of free electrons capable of drifting in a specific direction when subjected to a potential difference. For insulators with high resistance have a minimal amount of free electrons, making it difficult for them to move and for a current to flow.

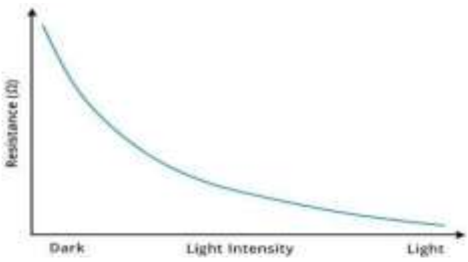


Figure 7. Variations in resistance to change in intensity:

An LDR or photoresistor is constructed using a semiconductor material with high resistance. Its high resistance arises from the lack of free electrons capable of movement. Most electrons are tightly bound within the crystal lattice and unable to migrate, resulting in a high resistance state for the LDR.

When light illuminates the semiconductor material, the photons within the light are absorbed by the lattice structure of the semiconductor. Some of the energy from the photons is transferred to the electrons within the material. This energy transfer provides a sufficient energy to some electrons, enabling them to break free from the crystal lattice and become capable of conducting electricity. Hence, the resistance of the semiconductor decreases, leading to a reduction in the overall resistance of the LDR.

Symbol of Light dependent Resistor: The symbol of a Light Dependent Resistor (LDR), also known as a photoresistor, consists of a standard resistor symbol (a rectangular box or zigzag line) with two arrows pointing towards it. These arrows represent incoming light, indicating that the resistor's resistance changes in response to light intensity. This symbol is commonly used in circuit diagrams to show components sensitive to light and is essential in designing automatic lighting systems, alarms, and light-sensitive switching applications

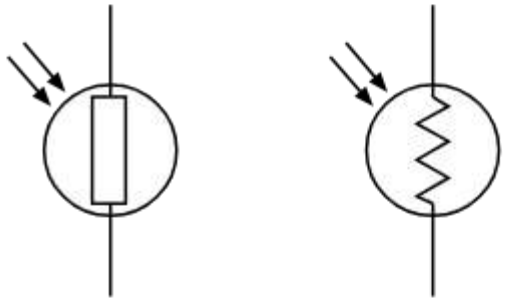


Figure 8. Symbol of Light dependent Resistor

Circuit of Light Dependent Resistor: The bridge rectifier circuit or a battery is used to provide the LDR circuit with the necessary DC voltage. This circuit converts the AC source to a DC source. To reduce the voltage from 230 volts to 12 volts, a step-down transformer is used in the bridge rectifier circuit.

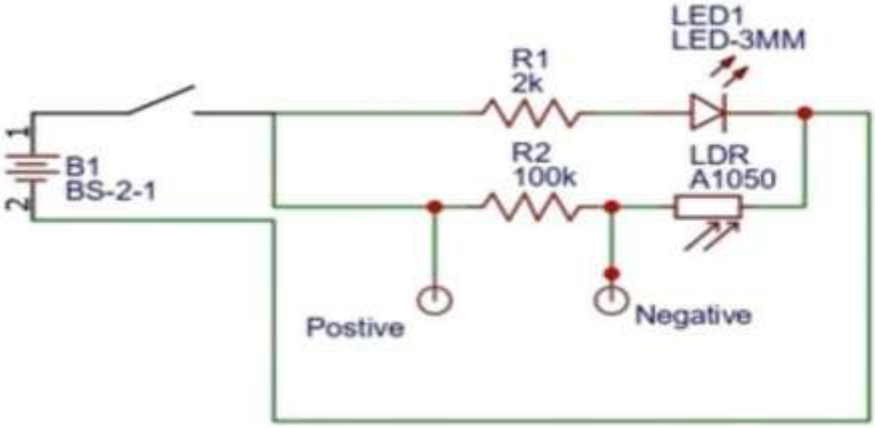


Figure 9. Circuit of Light Dependent Resistor

DC voltage is converted by connecting diodes in a bridge-like manner. The voltage regulator is utilized to transform the 12v DC to 6v DC, and the circuit is subsequently powered by this DC voltage. The bridge rectifier and load must both have a constant 230v AC supply for the light sensor circuit to operate constantly.

When the resistance is low around 100 Ωs. As can be seen in the light sensor circuit above, the power source passes through the LDR light sensor and ground through the variable resistor and resistor.

This is because the resistance provided by the light-dependent resistor is lower than the resistance of the remaining components of the sensor circuit during the day or when light is falling on the LD circuit. We are aware of the current principle, which states that current always flows in the direction of least resistance.

LDR and its characteristics: When light is incident on it, a photon is absorbed and thereby it excites an electron from valence band into conduction band. Due to such new electrons coming up in conduction band area, the electrical resistance of the device decreases. Thus the LDR or photo- conductive transducer has the resistance which is the inverse function of radiation intensity.

$\lambda_0 = \frac{hc}{e.E\omega}$

λ_0= threshold wavelength, in meters
e= charge on one electron, in Coulombs
$E\omega =$ work function of the metal used, in eV
Here we must note that any radiation with wavelength greater than the value obtained in above equation cannot produce any change in the resistance of this device.
The band gap energy of Cadmium Sulphide is 2.42 eV and for Cadmium Selenide it is 1.74eV. Due to such large energy gaps, both the materials have extremely high resistivity at room temperature such large energy gaps, both the materials have extremely high resistivity at room temperature.

Sensitivity of a LDR: The sensitivity of a photo detector is the relationship between the light falling on the device and the resulting output signal. In the case of a photocell, one is dealing with the relationship between the incident light and the corresponding resistance of the cell.

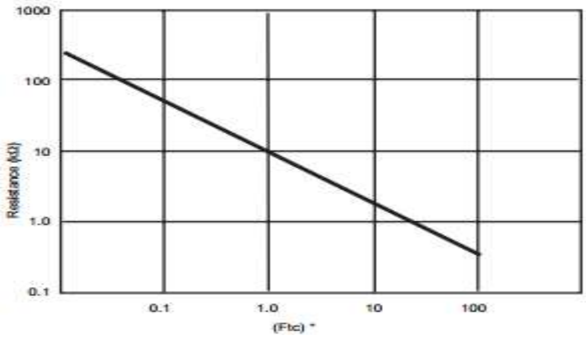


Figure. 10. Sensitivity of a LDR

Characteristics of Photoconductive Cells: Now when the device is kept in darkness, its resistance is called as dark 13 resistance. This resistance is typically of the order of 10 Ωs. When light falls on it, its resistance decreases up to several kilo Ωs or even hundreds of Ωs, depending on the intensity of light, falling on it.
The spectral response characteristics of two commercial cells were compared in our laboratory. And we found that there is almost no response to the radiation of a wavelength which was shorter than 300nm. It was very interesting to note that the Cadmium Sulphide cell has a peak response nearer or within the green color of the spectrum within a range of 520nm. Thus it can be used nearer to the infra-red region up to 750nm. It was found that the maximum response of Cadmium Sulphoselenide is in the yellow orange range at 615nm and also it can be used in the infra-red region up to about 970nm.

Spectral Response of a LDR:
Like the human eye, the relative sensitivity of a photoconductive cell is dependent on the wavelength (color) of the incident light. Each photoconductor material type has its own unique spectral response curve or plot of the relative response of the photocell versus wavelength of light.

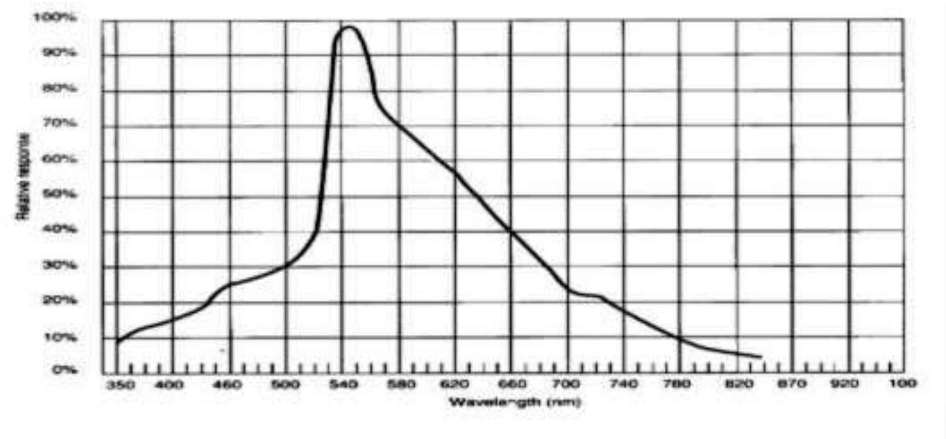


Figure 11. Spectral Distribution of LDR

Photoconductivity and Material Science: The fundamental phenomenon behind LDRs—photoconductivity is inherently linked to the material science of semiconductors. Most LDRs are made using cadmium sulfide (CdS) or cadmium selenide (CdSe), both of which are II–VI compound semiconductors. These materials have relatively narrow band gaps, allowing them to absorb photons in the visible light spectrum and generate charge carriers effectively.

The band gap of CdS Is about 2.42 eV, which corresponds to wavelengths in the visible region (around 512 nm). When light with energy greater than this band gap hits the surface of the LDR, electron-hole pairs are generated, resulting in increased electrical conductivity.

Several factors influence photoconductivity: The factors affecting the Photoconductivity are as follows:-

Wavelength of Incident Light: LDRs are most responsive to visible light, particularly blue and green light. Infrared and ultraviolet light may not produce the same response due to mismatch with the band gap energy.

Temperature: Photoconductivity is also thermally sensitive. Higher temperatures can increase thermal excitation, sometimes mimicking the effect of illumination and affecting accuracy.

Material Purity and Doping: Impurities in the semiconductor material can act as recombination centers, affecting the overall efficiency of photoconduction.

Types of LDR or photo resistor: LDRs are classified into two types based on the material used in the construction and methods of operation.

1. **Intrinsic LDR**
2. **Extrinsic LDR**

Intrinsic LDR (Undopped semiconductor): Intrinsic photoresistor use semiconductor materials like silicon or germanium that have not been doped with impurities. When photons strike the LDR, they excite electrons, causing them to excite from the valence band to the conduction band. This transition allows the electrons to move freely and conduct electricity. As more light reaches the device, a greater number of electrons are released, resulting in increased conductivity and a decrease in resistance.

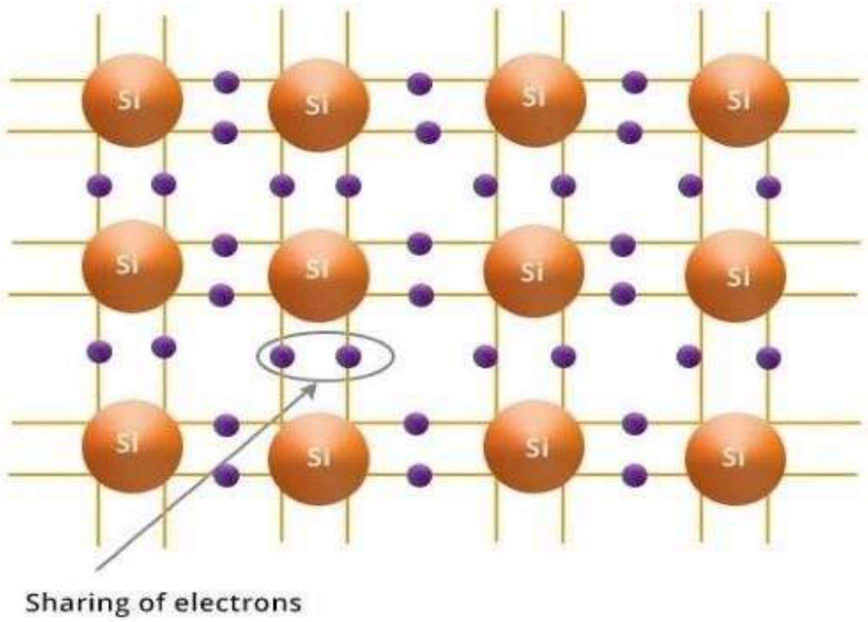


Figure 12. Sharing of electron in Pure Si Atom

Extrinsic LDR (doped semiconductor): Extrinsic photo resistors are created by adding impurities or dopants into the semiconductor materials. These dopants introduce a new energy band above the existing valence band. Hence, the electrons require less energy to move to the conduction band due to the reduced energy gap. With the presence of light, the electrons can easily move to the conduction band, enhancing conductivity and reducing resistance.

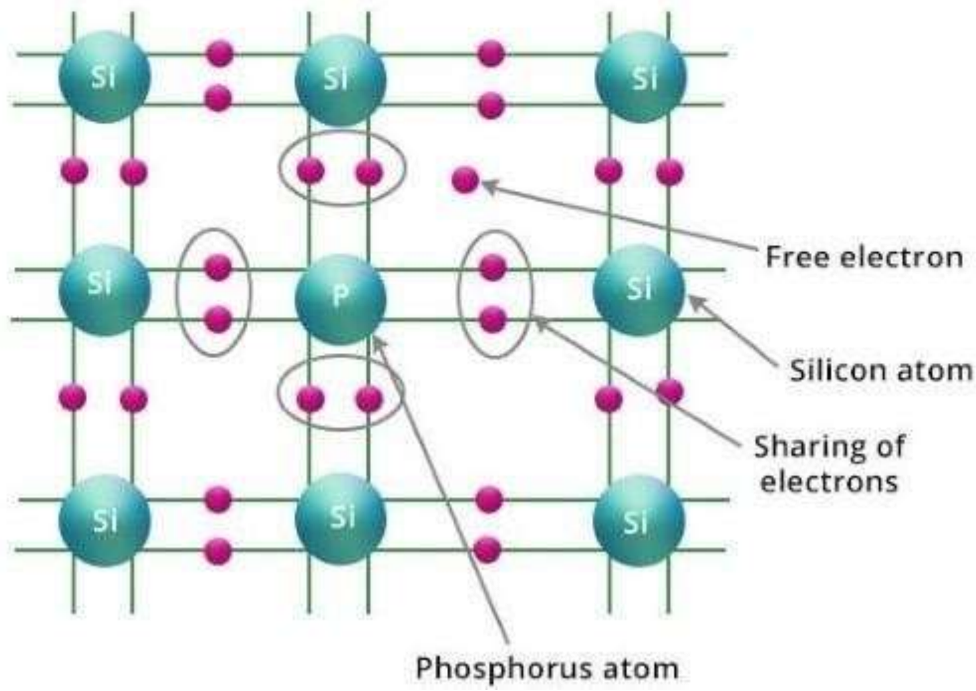


Figure 13. Sharing of electron in Impure Si Atom

1. **CdS Based LDRs:** The most commonly used type due to their reliable performance in the visible spectrum. They are ideal for ambient light detection.
2. **CdSe based LDRs:** These have a higher spectral response and can detect a broader range of light, including near-infrared.
3. **Flexible and Printed LDRs**: Emerging technologies using organic or printed semiconductors for flexible

electronics and wearables.

Each type varies in terms of resistance range, response time, spectral sensitivity, and cost. Selection depends on the specific application's requirements for light range, accuracy, and environmental conditions.

Factors Affecting LDR Response: The performance and response of LDRs depend on several environmental and electrical parameters:

- **Light Intensity:** As previously mentioned, the resistance of an LDR decreases with increasing light. However, the relationship is nonlinear and often follows a power-law curve.
- **Angle of Incidence:** The effective area exposed to light changes with angle, affecting the output. Systems requiring precision often include lenses or filters to control this.
- **Temperature:** Elevated temperatures can cause leakage currents in semiconductors, leading to erroneous readings. High-accuracy systems may need thermal compensation.
- **Wavelength of Light:** LDRs have spectral sensitivity curves and perform optimally within a certain wavelength range. Mismatched wavelengths may reduce responsiveness.
- **Aging and Environmental Exposure:** Prolonged exposure to high intensity light or UV rays can degrade the material, reducing efficiency over time.
- **Circuit Design:** Placement within the circuit, especially in voltage dividers, greatly influences the output signal and the linearity of the response.

Basics of Power Variation and Its Implications: Power variation in electronic systems refers to intentional or unintentional changes in the supplied voltage or current to a circuit. This can arise from source instability, energy-saving techniques, or deliberate testing procedures.

Effects on LDR Circuitry: In most cases, LDRs are passive elements and do not require a direct power supply. However, they are used in voltage divider configurations or analog input circuits where the power supplied affects the output voltage or current that the LDR influences. Therefore, variations in supply voltage can indirectly affect LDR based circuit readings.

For example, in a basic voltage divider:

$$V\{out\} = \frac{V\{in\} \times \{R\{LDR\}\}}{\{R\{LDR\}\} + \{R\{fixed\}\}}$$

Here, any variation in (input voltage) changes, making it difficult to isolate the LDR's true light-based response unless controlled.

Power Variation in Sensor Applications: Understanding how LDR-based systems perform under different power conditions is crucial for:

- **Battery-Operated Devices:** Where voltage drops as batteries deplete.
- **Renewable Energy Systems:** With fluctuating outputs based on sunlight or wind.
- **Low-Power IoT Devices:** Where sensor performance must remain consistent at suboptimal voltages.

Power variation can lead to increased noise, calibration drift, and signal instability. Therefore, analyzing the LDR's behavior under controlled power variation helps in designing voltage regulation circuits, software compensation algorithms, and hardware calibration routines.

III. METHODOLOGY

Summary of Past Research: The study of Light Dependent Resistors (LDRs) and their behavior under various illumination conditions has been an important area in electronics and sensor research. Over the years, LDRs have been evaluated in terms of spectral response, resistance changes, time constants, a nd long-term stability under continuous illumination. Numerous academic papers, industry white papers, and engineering projects have focused on optimizing the use of LDRs in low-cost light sensing applications.

One of the earliest uses of LDRs was documented in photoelectric sensors and analog light meters. As electronic components became more accessible, researchers began exploring the mathematical modeling of LDR behavior. These early studies primarily focused on the static response of the LDR—how resistance changed under different steady-state lighting conditions.

With advancements in microcontroller-based systems, researchers began integrating LDRs into adaptive lighting systems and environmental monitoring stations. These implementations necessitated deeper understanding of dynamic LDR behavior— how quickly and reliably an LDR could respond to changing light conditions.

A variety of studies have established that the resistance of an LDR approximately follows an inverse power-law relationship with light intensity:

$R = k.I^{-n}$

Where

R is the resistance, in Ωs,

I is the light intensity, in lux

K is a constant depending on specific material , construction and environmental factors and n is a empirical constant typically between 0.1 and 0.7

Studies on LDR Behavior under Variable Lighting: Several research efforts have analyzed how LDRs respond to varied light sources, including incandescent bulbs, fluorescent tubes, LEDs, and natural sunlight. These sources differ in spectral output, intensity fluctuation, and angle of emission, all of which affect the LDR's response. For instance, a 2018 study titled "Comparative Analysis of LDRs under Different Light Sources" explored how CdS-based LDRs responded to light from warm-white LEDs versus halogen bulbs. The findings revealed that response time was faster under halogen lighting, attributed to its higher thermal and spectral energy.

Another key study by R. Sharma et al. in IEEE Sensors Journal (2020) investigated the real- time response of LDRs in a simulated day-night cycle. The authors found that while LDRs tracked gradual changes effectively, they were less accurate in high-speed switching conditions due to latency in charge carrier recombination. Furthermore, experiments conducted at the University of Nairobi's Electrical Engineering Lab evaluated the impact of cloud cover on outdoor LDR sensors used for solar tracking.

Their report confirmed that scattered light caused by clouds significantly altered the resistance readings, necessitating filtering algorithms or dual-sensor setups for accurate readings.

Comparative Analysis of Previous Models:

Various models have been proposed to describe LDR response. These models differ in complexity based on the level of detail and application area. The most notable models include:

- **Linearized Resistance Models:** Useful for applications that do not require high precision. These models simplify the light resistance relationship and assume linearity over a narrow range.
- **Empirical Power-Law Models:** As mentioned earlier, these models are widely adopted and can be fitted using experimental data. Their flexibility makes them ideal for both low and high illumination levels.
- **Temperature-Compensated Models:** Developed for outdoor or industrial applications, these models factor in temperature induced changes in semiconductor conductivity.
- **SPICE-Compatible Circuit Models:** For simulation environments, researchers have built SPICE-compatible models that simulate the behavior of LDRs based on standard photoelectric equations. These models are particularly useful in designing and validating sensor-integrated analog circuits.

While each model has its use cases, they often fall short in applications where power supply variations are significant. This gap highlights the need for enhanced models that consider both illumination and voltage variations—something this research aims to address.

Limitations in Existing Studies: Despite the extensive research on LDRs, there are several limitations in current literature: Power Supply Stability Assumptions: Most studies assume a constant and ideal power source. This assumption is problematic when applying LDRs in systems with battery depletion or energy harvesting setups, where voltage is inherently unstable.

- **Lack of Dynamic Response Analysis:** While static light conditions are well-studied, real-world scenarios involve rapidly fluctuating lighting. Few studies delve into how quickly an LDR can adapt to changes or recover from saturation.
- **Material Constraints and Availability:** Due to environmental regulations, the use of cadmium (Cd) in electronics is becoming restricted in certain regions. Many studies have not explored alternative non-toxic materials or their implications on LDR design and behavior.
- **Simplistic Calibration Models:** Field-deployed LDR systems often rely on one-time calibration, which may not be valid under all conditions, particularly when power or temperature varies.
- **Inadequate Cross-Sensor Comparison:** Comparative studies between LDRs and other light sensors (e.g., photodiodes, phototransistors) are limited. Understanding how LDRs perform relative to modern alternatives could help in making informed sensor choices.
- **Integration with AI and Adaptive Systems:** There is minimal exploration of using AI or machine learning techniques to process LDR data for pattern recognition or adaptive control in smart lighting or automation systems**.**

Research Gap and Project Justification

The review of existing literature clearly demonstrates a knowledge gap regarding the behavior of LDRs under simultaneous variation of light intensity and power supply. Most research isolates one variable and studies its effect while holding others constant. However, real-world applications—such as in solar-powered or portable electronics— rarely offer such isolation. This research project seeks to bridge that gap by:

- Introducing a test environment that allows controlled variation of both power and light.
- Collecting empirical data to understand the interplay between illumination, resistance, and voltage supply.
- Developing a refined response model that integrates power variation parameters.
- Highlighting use-case implications for embedded system designers and engineers working in power-constrained environments.

By grounding this research in both foundational studies and the limitations identified in the literature, this project will contribute meaningfully to the evolving domain oflight sensitive sensors, particularly in the era of smart, energy-efficient, and portable technologies.

IV: Proposed Approach

Experimental Setup: To investigate the behavior of Light Dependent Resistors (LDRs) under varied illumination and power conditions, a controlled and repeatable experimental environment is essential.

The design of the setup focuses on isolating variables, ensuring accurate data acquisition, and simulating real-world use cases such as solar powered systems or ambient-light-controlled devices.

The key components of the experimental setup include:

- **LDR Sensor(s):** CdS-based LDRs with known resistance range (10 kΩ–1 MΩ) at specified lux levels.
- **Microcontroller:** An Arduino Uno or ESP32 microcontroller, chosen for its ADC capability and programmability.
- **Variable Light Source:** A calibrated LED array (white and RGB variants) with adjustable intensity using PWM (Pulse Width Modulation) for fine control.
- **Voltage Supply Unit:** A programmable DC power supply (0–12 V) used to emulate power variation.
- **Multimeter and Oscilloscope:** For real-time measurement of resistance, voltage, and response time.
- **Dark Enclosure:** A light-proof box to eliminate ambient interference and control lighting conditions

precisely.

- **Data Logging:** Arduino with serial output connected to a PC or SD card module for data recording.

This setup allows for both automated and manual control of illumination and voltage, while ensuring repeatability and precision.

Power Control and Variation Methodology: Inmost real-world applications, LDRs operate as part of a voltage divider circuit. The voltage across the LDR is used as an analog input to measure light intensity. However, if the supply voltage varies, this reading can be distorted. The purpose of the power variation methodology is to analyze this interaction.

Voltage Divider Circuit Design: The standard configuration is:

$$R_{LDR} = \frac{V_{out} \times R_{fixed}}{V_{in} - V_{out}}$$

Where:

V_{in} is the supply voltage, R_{fixed} is the resistance of the LDR (varies with light) Is a known resistor. This formula illustrates how both light (via) and power supply (via) impact .

Procedure for Power Variation:

Base Voltage Calibration: Begin by setting to a fixed 5V. Measure and log as light intensity is varied from 0 to 1000 lux.

Incremental Voltage Steps: Adjust in 1V steps from 3V to 9V. For each voltage level, repeat the light variation process.

Dynamic Variation: Introduce real-time power fluctuations (e.g., sinusoidal or random noise patterns) and observe LDR output.

This method enables correlation of LDR response with both voltage and light intensity, highlighting any nonlinearities or dependencies.

LDR Selection and Configuration: For this study, multiple LDRs were selected to observe variation between sensors of different quality and construction:

- Standard CdS LDR (5 mm, 10kΩ–1MΩ): Common in educational kits.
- High-Sensitivity LDR (precision type): Designed for lowlight detection.
- Encapsulated LDR (weatherproof): Used in outdoor automation.

Each LDR was tested under identical conditions. Their placement in the voltage divider was alternated (top vs. bottom) to see if orientation affects response. In addition, parallel and series combinations of LDRs were tested to observe aggregate behavior.

ADC Configuration:

- The Arduino's 10-bit ADC (Analog to Digital Converter) was calibrated using a precision voltage reference.
- Sampling rate was set to 50 samples per second.
- Averaging filters were applied to smooth the output.

Design Rationale:

This project's design decisions were guided by both theoretical principles and practical requirements. The rationale for each component is as follows:

1. **Microcontroller-Based Measurement:** Using a microcontroller allows for:

- Real-time processing and display of results.
- Fine control over light source and power supply.

- Easy integration with data logging mechanisms.

2. **Use of PWM for Light Control:** PWM (Pulse Width Modulation) enables dynamic and precise control of LED intensity, simulating varying sunlight or artificial lighting conditions. This is preferable to manual dimming, which is inconsistent and harder to replicate.
3. **Selection of Voltage Divider:** The voltage divider circuit allows for a straightforward analog read of light levels using an LDR. The position of the fixed resistor (above or below the LDR) changes the slope of the response curve, allowing the designer to prioritize either high or low light sensitivity
4. **Emphasis on Power Variation:** In real-world conditions, power sources are often unstable (battery-powered devices, solar panels, etc.). By incorporating power variation into testing, the project reflects realistic use cases and builds a robust data set.
5. **Data Logging and Analysis Tools:** To make accurate conclusions, the project uses CSV-format data logs analyzed in Python and Excel. Graphs, correlation plots, and time-domain responses help quantify the behavior of LDRs.
6. **Use of Multiple Sensor Types:** Testing across LDR types helps ensure that the findings are not limited to a specific brand or model, thereby increasing the applicability of results.

Experimental Phases: To ensure systematic testing, the research was divided into the following phases:

Phase 1: Calibration

- Establish baseline readings in complete darkness and full illumination.
- determine resistance range for each LDR.

Phase 2: Controlled Illumination

- Adjust light in uniform steps (e.g., 0, 100, 200 … 1000 lux).
- keep power supply fixed.
- Measure resistance and output voltage.

Phase 3: Power Variation

- Repeat Phase 2 across multiple power supply voltages.
- Identify how resistance-output correlation shifts.

Phase 4: Combined Variation

- Change both light and power levels dynamically.
- Log response time and sensitivity under changing conditions.

Phase 5: Edge Cases

- Sudden light removal (e.g., hand blocking source).
- Simulate day-night transitions.
- Introduce heat to evaluate temperature effects.

Expected Outcomes: Based on the proposed methodology, the following outcomes are anticipated:

Quantified Relationship: A detailed curve showing how LDR resistance and output voltage depend on light intensity across multiple voltage inputs.

Sensitivity Trends: Understanding of which LDR types are more stable under power fluctuations.

Design Guidelines: Practical insights into how to compensate for power variations in real-world LDR circuits.

Modeling Parameters: Updated constants for LDR behavior equations under varying voltages.

V: Experimentation and Results

Description of Experiments: This chapter presents the practical implementation of the proposed methodology, including step-by-step execution of experiments designed to evaluate LDR behavior under varying illumination and power supply conditions.

Objective: To empirically analyze how LDR resistance and output voltage behave with:

- Changes in light intensity (from darkness to ~1000 lux)

- Variations in power supply voltage (from 3V to 9V)
- Simultaneous changes in both Setup Recap:

LDRs: Three types tested (standard CdS, high-sensitivity, and encapsulated)
Microcontroller: Arduino Uno with 10-bit ADC
Light source: Dimmable LED array (PWM controlled)
Power supply: Programmable bench PSU (0–12V)
Measurement: Serial monitor logging via Arduino + multimeter for verification
The LDRs were connected in a voltage divider with a 10 kΩ fixed resistor. Output voltage was read using the Arduino's analog pin. A light meter (Lux Meter LX1330B) was used to measure the illumination level at the sensor's surface.

Data Collection and Analysis:
Phase 1: Fixed Power, Varying Light
At a constant power supply of 5V, the LDR resistance and resulting output voltage were measured at increasing illumination levels (from 0 to 1000 lux in 100 lux increments).

Light intensity	LDR Resistance	V_out (volt)
0	980	4.88
100	480	4.53
200	220	4.06
300	150	3.67
400	80	2.91
500	60	2.52
600	35	1.89
700	20	1.29
800	10	0.78
900	5	0.48
1000	2.5	0.27

Table: 1. Sample Table (Standard CdS LDR, Vin = 5V)

Observation:
The output voltage dropped non-linearly with increasing light. The curve followed an exponential decay profile, validating the theoretical inverse relationship between resistance and illumination.
Graph 1: V_{out} vs Light Intensity
Graph shows steep drop in voltage as lux increases

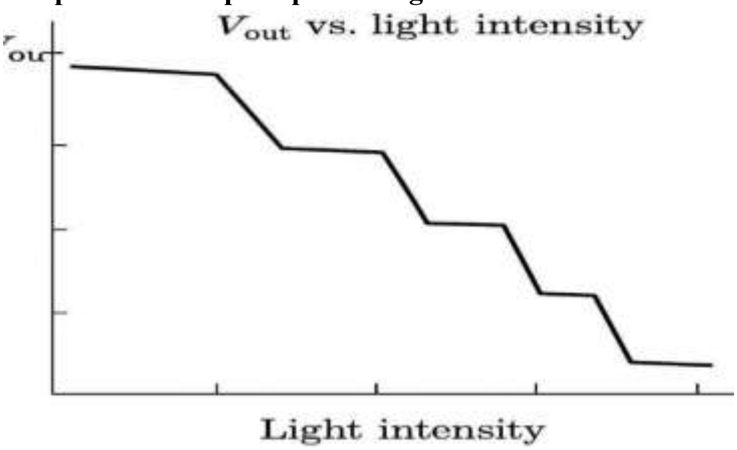


Figure V_{out} vs. Light Intensity
Phase 2: Varying Power, Fixed Light

The power supply was varied from 3V to 9V in 1V steps, keeping light intensity fixed at 500 lux. The objective was to observe how LDR output voltage responds when V_{in} changes, which simulates unstable or depleted power sources.

V_{in} (volt)	V_{out} (volt)
3.0	1.57
4.0	2.12
5.0	2.52
6.0	3.07
7.0	3.48
8.0	4.12
9.0	4.65

Table 2:

Observation:

LDR output voltage scaled almost linearly with input voltage, but slight nonlinearities appeared at lower voltages. This confirmed that power fluctuations can significantly affect analog readings from the LDR, even under constant lighting.

Phase 3: Combined Variation:

In this phase, both light and voltage were changed simultaneously. This mimicked real-world cases like solar-powered garden lights that experience both ambient and battery changes. The Arduino recorded output voltage every second for 60 seconds, during which the light was ramped up (0–1000 lux) and the voltage was varied between 3–9V in random patterns.

Graph 2: Real-time Output Voltage (Vout) vs. Time (Line graph with overlapping light and voltage values shown alongside)

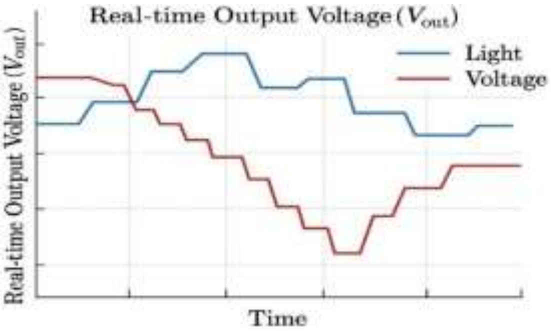


Figure:

Observation:

- Rapid changes in either variable caused brief instability in V_out.
- The output reading is significantly impacted by power source quality.
- Delays in response were observed, particularly in low-light transitions.

Phase 4: Response Time Testing

This test measured how quickly the LDR responded to sudden light changes. An LED was turned on/off using a relay, and the voltage response was logged with microsecond precision.

Result:

- Rise time: ~180 ms, Fall time: ~250 ms
- Faster response in brighter conditions; slower in dim-to-dark transitions

Conclusion:

Standard LDRs have a latency that must be considered in time-critical applications.

Graph 3: Resistance vs. Light Intensity
Shows inverse exponential trend for all three LDRs

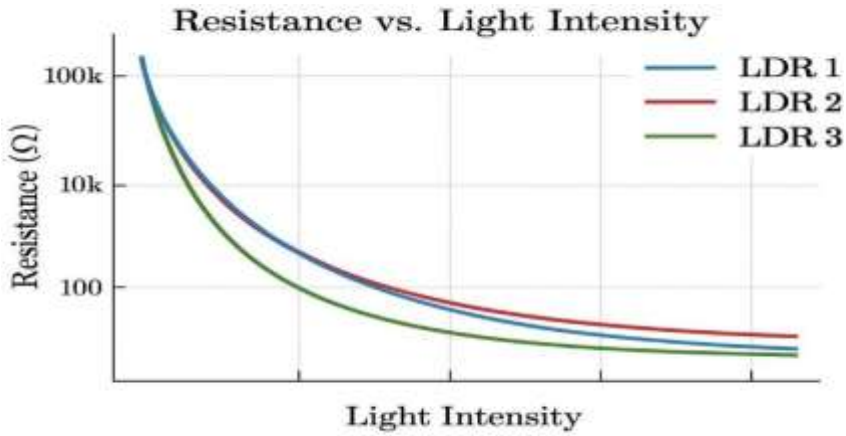


Figure: Resistance vs. Light Intensity

Graph 4: V_{out} vs. Light (at multiple V_{in} values)
Overlay graph showing how each voltage level changes the Vout curve

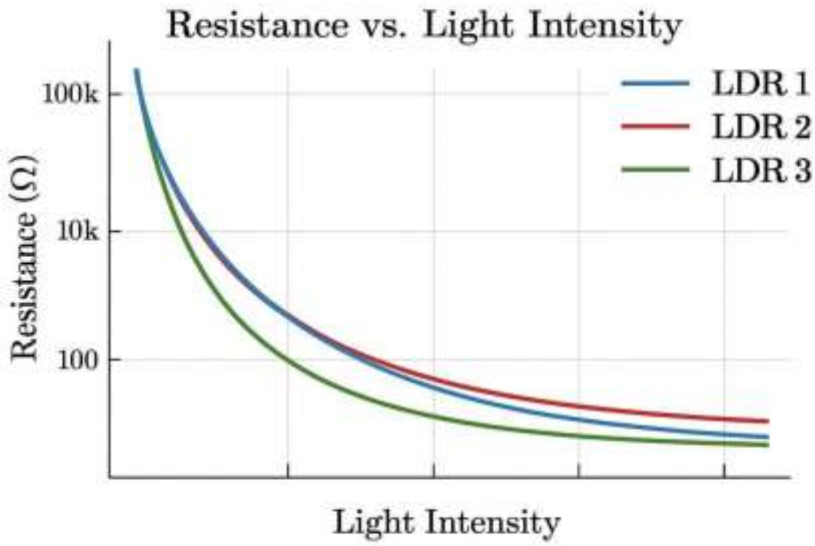


Figure: **V_{out} vs. Light (at multiple V_{in} values)**

Graph 5: Comparison of LDR Types

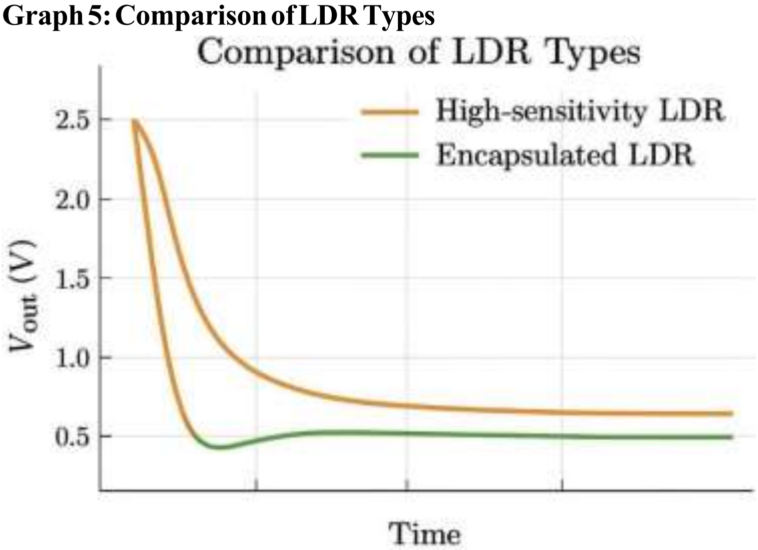


Figure : Comparison of LDR Types

High-sensitivity LDR showed quicker response and higher resolution in low-light. Encapsulated LDR had slightly dampened response but better stability over time.

Discussion of Results

1. **Power Dependence:** LDR voltage readings are highly sensitive to power supply changes. Systems using LDRs must either stabilize V_in or implement calibration to correct readings.
2. **Non-linear Behavior:** The resistance of an LDR does not change linearly with lux. Most accurate readings occur between 100–800 lux. Outside this range, saturation or underflow occurs.
3. **Suitability of LDR Types:**
- **Standard CdS LDR:** Suitable for mid-range light detection.
- **High-sensitivity:** Better for low-light or precision tasks.
- **Encapsulated**: Best for outdoor/harsh environments.
4. **Effect of Configuration:**
- Changing resistor values in the voltage divider adjusts sensitivity range.
- Reversing LDR/resistor placement shifts the voltage-lux curve.
5. **Real-Time Use Implications:**
- LDRs should not be used in high-speed light detection without accounting for latency.
- Analog-to-digital conversion must be carefully calibrated for the voltage source.
6. **Limitations Encountered**
- ADC noise at low voltages impacted accuracy.
- Light reflections and scattering sometimes skewed results in unshielded setup.
- Temperature fluctuation during extended tests may have altered LDR response

Chapter 6
Conclusion and Future Scope

This research comprehensively investigated the behavior of Light Dependent Resistors (LDRs) under varying illumination levels and supply voltage conditions. The findings derived from theoretical analysis, experimental procedures, and data interpretation offer several significant insights into how LDRs function in dynamic environments.

1. **Voltage Output Is Highly Sensitive to Power Supply Variations:** In a voltage divider configuration, output voltage (V_out) is directly proportional to the supply voltage (V_in). If the power source fluctuates, the voltage reading across the LDR also shifts, even if light conditions remain unchanged.
2. **Performance Varies by LDR Type:** Different LDRs exhibit varied sensitivity and response characteristics. High sensitivity models respond faster and more accurately in lowlight conditions, whereas weatherproof LDRs provide consistent readings but with slightly dampened responsiveness.
3. **Response Time Limitations:** Standard LDRs exhibit response times in the range of 180–250 milliseconds, making them unsuitable for high-speed light detection applications. However, they remain effective for applications where rapid transitions are not critical.
4. **Combined Power and Light Variability Impacts Accuracy:** In real-time tests involving simultaneous light and power variations, LDRs demonstrated compounded response errors. This underlines the importance of power stabilization or digital compensation techniques in practical circuit design.

Evaluation Against Objectives

The objectives defined at the outset of this study included:

- **Understanding LDR response to illumination:** This objective was fully achieved. The resistance-voltage behavior across a wide range of lux levels was documented and analyzed.
- **Exploring power variation effects on LDR behavior:** Systematic testing across different power levels

clearly demonstrated that unstable voltage can significantly distort LDR readings, an area often overlooked in basic circuit design.

- **Developing a realistic experimental approach:** The project designed and implemented a reliable, replicable test environment incorporating microcontroller-based data logging, PW controlled illumination, and precise power regulation.

Each of these goals was not only met but also yielded data that can inform engineering design decisions involving LDRs.

Potential Applications: Based on the insights from this project, LDRs continue to hold significant value in a variety of applications, provided their limitations are acknowledged and mitigated:

- **Street Lighting Automation:** By placing LDRs in outdoor fixtures, lights can be triggered at dusk or dawn. However, voltage regulation is critical to ensure reliable operation.
- **Consumer Electronics:** LDRs are often used in devices such as automatic screen dimmers and smart lamps. Accurate performance depends on well-calibrated analog readings and controlled power environments.
- **Agricultural Monitoring Systems:** For greenhouse or crop monitoring solutions, LDRs offer a cost-effective means to track light levels throughout the day.
- **Solar-Powered Devices:** Since these devices are inherently subject to power fluctuations, understanding the power- illumination interaction is essential for system reliability.
- **Educational Tools:** The simplicity and visibility of LDR operation make them ideal for use in STEM education and learning kits.

Suggestions for Future Research: This project opens the door to a number of follow-up studies and improvements:

- **Temperature Sensitivity Analysis:** LDRs are known to be thermally sensitive. Future work should quantify how ambient temperature affects resistance and response speed.
- **Digital Compensation Algorithms:** Building a microcontroller based calibration model that adjusts LDR readings based on real-time power levels could significantly improve accuracy.
- **Integration with IoT Systems:** LDRs could be integrated with IoT platforms for remote light monitoring. Future studies could evaluate communication efficiency and battery longevity.
- **Exploring Alternative Materials:** Most LDRs are based on CdS (cadmium sulfide), a material with known environmental risks. Research into alternative photoconductive materials such as PbS or GaAs might provide eco-friendlier or more sensitive options.
- **Response Optimization Techniques:** Experiments could be done to test how filters, amplifiers, or circuitry modifications affect response time and stability in real-world applications.
- **Machine Learning-Based Prediction Models:** AI techniques could be trained to predict true light intensity from noisy LDR output under fluctuating power scenarios, improving system intelligence and error tolerance.

Final Thoughts: The study reaffirmed that while LDRs are simple and cost-effective light sensors, their behavior under varying illumination and power conditions is complex and deserves careful consideration. For hobbyists, engineers, or researchers developing light-sensitive systems, understanding these nuances is critical to building reliable and precise devices.

This project contributes not only to academic understanding but also offers practical design implications for a wide array of real world applications, bridging the gap between theory and practice in sensor-based system development.

Summary

This research project, titled "A Study on the Illumination of Light Dependent Resistors (LDRs) with Power Variation," aimed to investigate how LDRs respond to varying light intensities under different power supply conditions. Through theoretical background study, review of related work, experimental design, and data analysis, this study provides a comprehensive understanding of LDR behavior in both ideal and real-world scenarios.

The project began with an Introduction that established the importance of LDRs in modern electronics, especially in applications such as automatic lighting, solar tracking systems, and light-based detection mechanisms. The objectives of the project were clearly outlined: to examine the illumination resistance relationship of LDRs, assess the effects of power variation on output, and propose an experimental approach that delivers actionable insights.

In the Background Details, the working principle of LDRs was explained in depth. Based on the concept of photoconductivity, LDRs decrease in resistance when exposed to increased light. Material science principles were explored, particularly the role of cadmium sulfide (CdS) in standard LDR construction. The chapter also covered various LDR types and external factors affecting their performance, including temperature, response time, and mechanical design. The section concluded with a review of power supply theory and how fluctuations can impact analog circuit behavior. The Related Work chapter surveyed "existing research and practical implementations involving LDRs. Prior studies were evaluated to identify the scope of investigation and limitations of those efforts. While some studies focused solely on illumination or resistance, few considered the dual impact of power variation. Gaps were noted in calibration methods and environmental modeling, establishing a clear rationale for the proposed research.

The Proposed Approach chapter described the experimental setup in detail. It included information about LDR selection, voltage divider configuration, light control using PWM-based LEDs, and data collection via an Arduino microcontroller. The chapter also explained how variations in power were introduced and controlled using a programmable power supply. A systematic method was laid out to test LDR response across a range of lux levels and voltages, simulating both ideal and variable real-world conditions.

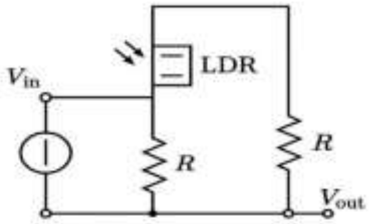
The Experimentation and Results chapter reported findings from three major test phases: constant voltage with variable light, constant light with variable voltage, and combined variation. Data showed a strong inverse exponential relationship between light intensity and resistance. Output voltage was affected not only by illumination but also significantly by supply voltage. LDRs of different types showed variations in sensitivity and response time. Graphs and data tables confirmed the impact of external variables, with implications for real-time sensor deployment.

Finally, the Conclusion and Future Scope summarized the key insights, evaluated the success of the project objectives, and suggested future research directions. These include exploring digital compensation, testing alternate materials, and integrating machine learning for predictive calibration.

Overall, this study confirms that while LDRs are simple components, their performance is influenced by a variety of factors. Reliable use in engineering systems requires a nuanced understanding of both light and power dynamics, and this project provides a foundational guide to that understanding.

Appendix A:

1. Circuit Diagrams:



Basic LDR Voltage Divider Circuit

Explanation: The LDR and fixed resistor form a voltage divider. As light increases, the resistance of the LDR decreases, lowering V_out. V_out is measured by a microcontroller to infer light intensity.

2. Arduino Code:

Purpose: This script reads the voltage across the LDR and prints the value to the Serial Monitor for real-time observation.

3. LDR Datasheets (Summarized)

3.1. Standard CdS LDR (GL5528) Parameter Value

- Dark resistance > 1 MΩ
- Light resistance (@10 lux) ~10–20 kΩ
- Peak spectral response =540 nm
- Response time Rise: 20–30 ms,
- Fall: 30–50 ms
- Max Voltage =150 VDC
- Operating Temp Range =-30°C to +70°C

3.2. High Sensitivity LDR (GL5537) Parameter Value

- Dark resistance > 2 MΩ
- Light resistance (@10 lux) ~8–15 kΩ
- Peak spectral response = 560 nm
- Response time faster than GL5528
- Ideal for Low-light environments.

3.3. Encapsulated Outdoor LDR Parameter Value

- Light resistance (@100 lux) =~5–10 kΩ
- Encapsulation Epoxy/resin (weatherproof)

- UV resistant,
- Ideal for Outdoor sensing applications.

4. Raw Data Tables

4.1. Light Intensity vs. V_{OUT} (V_{IN} = 5V)

Lux Resistance (kΩ)	**V_{in}**	**V_{out}**
0	980	4.88
100	480	4.53
200	220	4.06
300	150	3.67
400	80	2.91
500	60	2.52
600	35	1.89
700	20	1.29
800	10	0.78
900	5	0.48

4.2. V_{in} Variation at Constant Light (500 lux)

V_{in} (V)	**V_{out} (V)**
3.0	1.57
4.0	2.12
5.0	2.52
6.0	3.07
7.0	3.48
8.0	4.12
9.0	4.65

5. Additional Notes

Tools Used:

- Arduino Uno
- LX1330B Lux Meter
- Benchtop Power Supply
- Dimmable LED Panel

Sampling Interval: 0.5–1 second depending on test phase.

Environmental Conditions: Temperature maintained at ~25°C, tests conducted in a dark room with controlled lighting.

Appendix B:
Technical Specifications of Light Dependent Resistor (LDR)
A Light Dependent Resistor (LDR), also known as a photoresistor, is a passive electronic Component that changes its resistance based on the intensity of incident light.

Material and Construction: LDRs are typically made from semiconductor materials such as cadmium sulfide (CdS) or cadmium Selenide (CdSe). The active material is deposited in a zigzag pattern on an insulating substrate to Increase the surface area.

Electrical Characteristics:
- **Dark Resistance:** Several megaohms (MΩ) in total darkness
- **Light Resistance:** A few hundred ohms (Ω) in bright light
- **Spectral Response:** Peak sensitivity in the 520-600 nm range
- **Response Time:** Rise time about 10-100 ms
- **Fall time**: Around 100- 200 ms
- **Voltage Rating:** Around 150V max
- **Power Dissipation:** 50 to 100 mW

Environmental Parameters
Operating Temperature Range: 30° C to +70°C
Storage Temperature: 40°C to +100° C
Humidity Tolerance: Must be kept dry

Typical LDR Types –
- GL5528
- NSL19
- VT90N2

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