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Clear View on Optical Detectors in Ultravoilet Visible and Infrared Portions of the Electromagnetic Spectrum in a Light Wave Communication

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Abstract-Many optical fiber communication applications require the use of optical radiation detectors. Examples are optical radar, monitoring of laser power levels for materials processing, and laser metrology. There are different types of optical fiber detectors are available, these optical fiber detectors are covering the ultraviolet, visible, and infrared portions of the electromagnetic spectrum. Optical detectors convert incoming optical energy into electrical signals. Thee are two main types of optical fiber detectors are available, such as photon detectors and thermal detectors. Photon detectors produce one electron for each incoming photon of optical energy. The electron is then detected by the electronic circuitry. Thermal detectors convert the optical energy to heat energy, which then generates an electrical signal.. The incident light changes the characteristics of the detector and changes the current flowing in the circuit. The output signal is then the change in voltage drop across the load resistor.

In this article, I am describing Fiber optic communication, Electromagnetic spectrum, optical detectors and their important characteristics in photonic applications.

Keywords: optical detectors readout concepts, Thermal detectors,

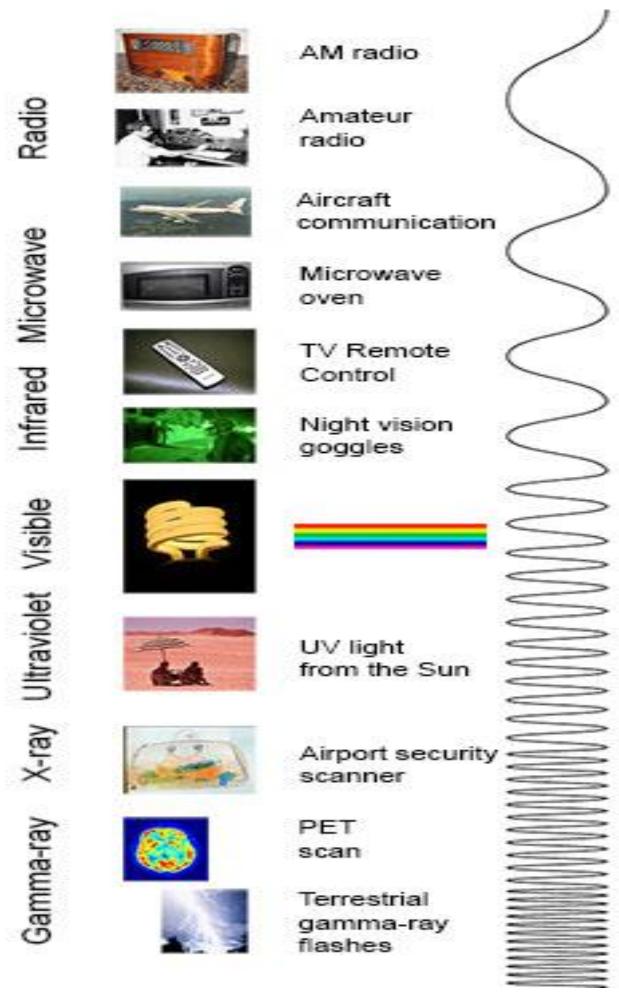
I. INTRODUCTION

Fiber-optic communication: It is an advanced technology of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. It was first developed in the 1970s, fiber-optic communication systems are widely using in the telecommunications industry and have played a major role in the advent of the Information Age. Because of its advantages over electrical_transmission, optical fibers have largely replaced copper wire communications in core networks in the developed world. The process of communicating using fiber-optics involves the following basic steps:

Creating the optical signal involving the use of a transmitter, relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak, receiving the optical signal, and converting it into an electrical signal.

Electromagnetic Spectrum: The electromagnetic (EM) spectrum is the range of all types of EM radiation. Radiation is energy that travels and spreads out as it goes – the visible light that comes from a lamp in your house and the radio waves that come from a radio station are two types of electromagnetic radiation.

The other types of EM radiation that make up the electromagnetic spectrum are microwaves, infrared light, ultraviolet light, X-rays and gamma-rays. The image below shows each portion of the EM spectrum in our day-to-day life.



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The electromagnetic spectrum from lowest energy/longest wavelength (at the top) to highest energy/shortest wavelength (at the bottom)

Radio: radio captures radio waves, emitted by radio stations, bringing favorite tunes. Radio waves are also emitted by stars and gases in space.

Microwave: Microwave radiation will cook your popcorn in just a few minutes, but is also used by astronomers to learn about the structure of nearby galaxies.

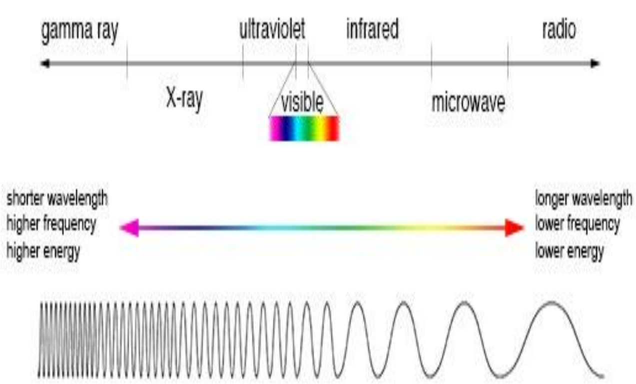
Infrared: Night vision goggles pick up the infrared light emitted by our skin and objects with heat. In space, infrared light helps us map the dust between stars.

Visible: Our eyes detect visible light. Fireflies, light bulbs, and stars all emit visible light.

Ultraviolet: Ultraviolet radiation is emitted by the Sun and is the reason skin tans and burns. "Hot" objects in space emit UV radiation as well.

X-ray: A dentist uses X-rays to image your teeth, and airport security uses them to see through your bag. Hot gases in the Universe also emit X-rays.

Gamma ray: Doctors use gamma-ray imaging to see inside your body. The biggest gamma-ray generator of all is the Universe.



Regions of the Electromagnetic Spectrum

Listed below are the approximate wavelength, frequency, and energy limits of the various regions of the electromagnetic spectrum.

	Wavelength (m)	Frequency (Hz)	Energy (J)
Radio	$> 1 \times 10^{-1}$	$< 3 \times 10^{9}$	$< 2 \times 10^{-24}$
Microwave	$1 \times 10^{-3} - 1 \times 10^{-1}$	$3 \times 10^{9} - 3 \times 10^{11}$	$2 \times 10^{-24} - 2 \times 10^{-22}$
Infrared	$7 \times 10^{-7} - 1 \times 10^{-3}$	$3 \times 10^{11} - 4 \times 10^{14}$	$2 \times 10^{-22} - 3 \times 10^{-19}$
Optical	$4 \times 10^{-7} - 7 \times 10^{-7}$	$4 \times 10^{14} - 7.5 \times 10^{14}$	$3 \times 10^{-19} - 5 \times 10^{-19}$
UV	$1 \times 10^{-8} - 4 \times 10^{-7}$	$7.5 \times 10^{14} - 3 \times 10^{16}$	$5 \times 10^{-19} - 2 \times 10^{-17}$
X-ray	$1 \times 10^{-11} - 1 \times 10^{-8}$	$3 \times 10^{16} - 3 \times 10^{19}$	$2 \times 10^{-17} - 2 \times 10^{-14}$
Gamma-ray	$< 1 \times 10^{-11}$	$> 3 \times 10^{19}$	$> 2 \times 10^{-14}$

A. Optical Detectors:

When light strikes special types of materials, a voltage will generate, a change in electrical resistance may occur, or electrons may be ejected from the material surface. As long as the light is present, the condition continues. It ceases when the light is turned off. Any of the above conditions may be used to change the flow of current or the voltage in an external circuit and thus may be used to monitor the presence of the light and to measure its intensity.

B. Role of an optical detector:

Many photonics applications require the use of optical detectors to measure optical power or energy. In laser-based fiber optic communication, a detector is employed in the receiver. In laser materials processing, a detector monitors the laser output to ensure reproducible conditions. In applications involving interferometry, detectors are used to measure the position and motion of interference fringes. In most applications of light, one uses an optical detector to measure the output of the laser or other light source. Thus, good optical detectors for measuring optical power and energy are essential in most applications of photonics technology.

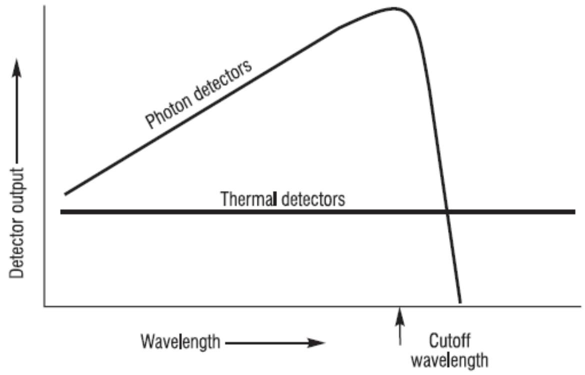
Optical detectors respond to the power in the optical beam, which is proportional to the square of the electric field associated with the light wave. Optical detectors therefore are called “square-law detectors.” This is in contrast to the case of microwave detectors, which can measure the electric field intensity directly. All the optical detectors that we will describe have square-law responses. Detection and measurement of optical and infrared radiation is a well-established area of technology. This technology has been applied to photonics applications. Detectors particularly suitable for use with lasers have been developed. Some detectors are packaged in the format of power or energy meters. Such a device is a complete system for measuring the output of a specific class of lasers, and includes a detector, housing, amplification if necessary, and a readout device.

II. TYPES OF OPTICAL DETECTORS.

Optical detectors are usually divided into two broad classes: photon detectors and thermal detectors. In photon detectors, quantum of light energy interacts with electrons in the detector material and generates free electrons. To produce free electrons, the quanta must have sufficient energy to free an electron from its atomic binding forces. The wavelength response of photon detectors shows a long-wavelength cutoff. If the wavelength is longer than the cutoff wavelength, the photon energy is too small to produce a free electron and the response of the photon detector drops to zero.

Thermal detectors respond to the heat energy delivered by light. These detectors use some temperature-dependent effect, like a change of electrical resistance. Because thermal detectors rely on only the total amount of heat energy reaching the detector, their response is independent of wavelength. The output of photon detectors and thermal detectors as a function of wavelength is shown schematically in Figure This figure shows the typical spectral dependence of the output of photon detectors, which increases with increasing wavelength at wavelengths shorter than the cutoff wavelength.

At that point, the response drops rapidly to zero. The figure also shows how the output of thermal detectors is independent of wavelength, and extends to longer wavelengths than the response of photon detectors.



Figure

The above figure is a Schematic drawing of the relative output per unit input for photon detectors and thermal detectors as a function of wavelength. The position of the long-wavelength cutoff for photon detectors is indicated.

The above figure is intended to show only the relative shape of the output curves for these two types of detectors and is not intended to show quantitative values. Quantitative values will be presented in later figures for some specific detectors.

Photon detectors may be further subdivided according to the physical effect that produces the detector response. Some important classes of photon detectors are listed below.

• *Photoconductive*. The incoming light produces free electrons which can carry electrical current so that the electrical conductivity of the detector material changes as a function of the intensity of the incident light. Photoconductive detectors are fabricated from

Semi conductor materials such as silicon.

• *Photovoltaic*. Such a detector contains a junction in a semiconductor material between a region where the conductivity is due to electrons and a region where the conductivity is due to holes (so-called pn junction). A voltage is generated when optical energy strikes the device.

• *Photo emissive*. These detectors are based on the photoelectric effect, in which incident photons release electrons from the surface of the detector material. The free electrons are then collected in an external circuit.

Photoconductive and photovoltaic detectors are commonly used in circuits in which there is a load resistance in series with the detector. The output is read as a change in the voltage drop across the resistor.

III DETECTOR CHARACTERISTICS

The performance of optical detectors is commonly characterized by a number of different parameters. It is important to define these parameters, sometimes called *figures of merit*, because manufacturers usually describe the performance of their detectors in these terms.

The figures of merit were developed to describe the performance of detectors responding to a small signal in the presence of noise. Thus, some of the figures of merit may not be highly relevant to the detection of laser light. For many laser applications, like laser metalworking, there is no question of detection of a small signal in a background of noise. The laser signal is far larger than any noise source that may be present. In other photonics applications, like laser communication, infrared thermal imaging systems, and detection of backscattered light in laser remote sensing, the signals are small and noise considerations are important.

C. Responsivity

The first term that we will define is *responsivity*. This is the *detector output per unit of input power*. The units of responsivity are either amperes/watt (alternatively milliamperes/mill watt or microamperes/microwatt, which are numerically the same) or volts/watt, depending on whether the output is an electric current or a voltage.

The responsivity is an important parameter that is *usually specified by the manufacturer*.

Knowledge of the responsivity allows the user to determine how much detector signal will be available for a specific application

D. Noise Equivalent Power

A second figure of merit, which depends on noise characteristics, is the *noise equivalent power* (*NEP*). This is defined as the *optical power that produces a signal voltage (or current) equal to the noise voltage (or current) of the detector*. The noise is dependent on the bandwidth of the measurement, so that bandwidth must be specified. Frequently it is taken as 1 Hz. The equation defining *NEP* is

$$NEP = \frac{HA\,V_N}{V_S(\Delta f)^{1/2}}$$

where *H* is the irradiance incident on the detector of area *A*, *V*N is the root mean square noise voltage within the measurement bandwidth Δ*f*, and *V*S is the root mean square signal voltage.

Example problem:

The noise equivalent power of a detector with area 1 cm2 is measured to be 2 × 10–8 watts/(Hz)1/2 with a bandwidth of 1 Hz. What power is incident on the detector if the ratio of the noise voltage to the signal voltage is 10–6?

Solution:

According to Equation 6-1, the irradiance H at the detector must be

$$H = \frac{NEP}{A\left(\frac{V_N}{V_S}\right)\frac{1}{(\Delta f)^{1/2}}} = 2 \times 10^{-8}/\{(1) \times (10^{-6}) \times (1)\} = 0.02\ \text{W/cm}^2$$

Because the area of the detector was 1 cm2, the power is 0.02 W.

E. Detectivity:

The *NEP* of a detector is dependent on the area of the detector. To provide a figure of merit that is dependent on the intrinsic properties of the detector, not on how large it happens to be, a term called detectivity is defined.

Detectivity is represented by the symbol *D**, which is pronounced as D-star. It is defined as the *square root of the detector area per unit value of* NEP.

*D** = *A*1/2/*NEP*

Since many detectors have *NEP* proportional to the square root of their areas, *D** is independent of the area of the detector. The detectivity thus gives a measure of the intrinsic quality of the detector material itself.

When a value of *D** for an optical detector is measured, it is usually measured in a system in which the incident light is modulated or chopped at a frequency *f* so as to produce an AC signal, which is then amplified with an amplification bandwidth Δf. These quantities must also be specified. The dependence of *D** on the wavelength λ, the frequency *f* at which the measurement is made, and the bandwidth Δf are expressed by the notation *D**(λ,*f*,*Df*). The reference bandwidth is often 1 Hertz. The units of *D**(λ,*f*,*Df*) are cm-Hz1/2/watt. A high value of *D**(λ,*f*,*Df*) means that the detector is suitable for detecting weak signals in the presence of noise. Later, in the discussion of noise, we will describe the effect of modulation frequency and bandwidth on the noise characteristics.

Example problem:

A detector has a noise equivalent power of 3 × 10–9 watts/(Hz)1/2 and an area of 0.4 cm2. What is its value of *D**?

Solution:

According to equation 6-2, *D** is (0.4 cm2)1/2/3 × 10–9 watts/(Hz)1/2

= 0.632 cm × 0.333 ×109 Hz1/2/watt

= 2.11 × 108 cm-Hz1/2/watt

F. Quantum efficiency:

Another common figure of merit for optical detectors is the *quantum efficiency*. Quantum efficiency is defined as the *ratio of countable events produced by photons incident on the detector to the number of incident photons*. If the detector is a photo emissive detector that emits free electrons from its surface when light strikes it, the quantum efficiency is the number of free electrons divided by the number of incident photons. If the detector is a semiconductor pn-junction device, in which hole-electron pairs are produced, the quantum efficiency is the number of hole-electron pairs divided by the number of incident photons. If, over a period of time, 100,000 photons are incident on the detector and 10,000 hole-electron pairs are produced, the quantum efficiency is 10%.

The quantum efficiency is basically another way of expressing the *effectiveness of the incident optical energy for producing an output of electrical current*. The quantum efficiency *Q* (in percent) may be related to the responsively by the equation:

$Q = 100 \times Rd \times (1.2395/\lambda)$ (6-3) where *Rd* is the responsively (in amperes per watt) of the detector at wavelength λ (in micrometers).

Example problem:

A detector has a quantum efficiency of 10% at a wavelength of 500 nm. At a wavelength of 750 nm, the responsively is twice the responsively at 500 nm. What is the quantum efficiency at 750 nm?

Solution:

From Equation 6-3, we see that the increase in responsively from 500 to 750 nm will increase the quantum efficiency *Q* by a factor of 2, but the increase in wavelength will decrease the quantum efficiency *Q* by a factor of 2/3, so that the net change in quantum efficiency will be an overall increase by a factor of 4/3, from 10% to 13.33%.

G. Detector response time

Another useful detector characteristic is the *speed of the detector response* to changes in light intensity. If a light source is instantaneously turned on and irradiates an optical detector, it takes a finite time for current to appear at the output of the device and for the current to reach a steady value. If the source is turned off instantaneously, it takes a finite time for the current to decay back to zero. The term *response time* refers to the *time it takes the detector current to rise to a value equal to 63.2% of the steady-state value* which is reached after a relatively long period of time. (This value is numerically equal to 1 – 1/*e*, where *e* is the base of the natural logarithm system.) The *recovery time* is the *time it takes for the photocurrent to fall to 36.8% of the steady-state value* when the light is turned off instantaneously.

Because optical detectors often are used for detection of fast pulses, another important term, called *rise time*, is often used to describe the speed of the detector response. *Rise time* is defined as the *time difference between the point at which the detector has reached 10% of its peak output and the point at which it has reached 90% of its peak response*, when it is irradiated by a very short pulse of light. The *fall time* is defined as the *time between the 90% point and the 10% point on the trailing edge of the pulse waveform.* This is also called the decay time. We should note that the fall time may be different numerically from the rise time.

Of course, light sources are not turned on or off instantaneously. To make accurate measurements of rise time and fall time, the source used for the measurement should have a rise time much less that the rise time of the detector being tested. Generally, one should use a source whose rise time is less than 10% of the rise time of the detector being tested.

The intrinsic response time of an optical detector arises from the transit time of photo generated charge carriers within the detector material and from the inherent capacitance and resistance associated with the device. The measured value of response time is also affected by the value of the load resistance that is used with the detector, and may be longer than the inherent response time. There is a tradeoff in the selection of a load resistance between speed of response and high sensitivity. It is not possible to achieve both simultaneously. Fast response requires a low load resistance (generally 50 ohms or less).,. whereas high sensitivity requires a high value of load resistance. It is also important to keep any capacitance associated with the circuitry, the electrical cables, and the display devices as low as possible. This will help keep the *RC* (resistance × capacitance) time constant low. Manufacturers often quote nominal values for the rise times of their detectors.

These should be interpreted as minimum values, which may be achieved only with careful circuit design and avoidance of excess capacitance and resistance in the circuitry.

H. Linearity:

Yet another important characteristic of optical detectors is their *linearity*. Detectors are characterized by a response in which the *output is linear with incident intensity*. The response may be linear over a broad range, perhaps many orders of magnitude. If the output of the detector is plotted versus the input power, there should be no change in the slope of the curve.

Noise will determine the lowest level of incident light that is detectable. The upper limit of the input/output linearity is determined by the maximum current that the detector can produce without becoming saturated. *Saturation* is a condition in which there is *no further increase in detector response as the input light intensity is increased*. When the detector becomes saturated, one can no longer rely on its output to represent the input faithfully. The user should ensure that the detector is operating in the range in which it is linear.

Manufacturers of optical detectors often specify maximum allowable continuous light level.

Light levels in excess of this maximum may cause saturation, hysteresis effects, and irreversible damage to the detectors. If the light occurs in the form of a very short pulse, it may be possible to exceed the continuous rating by some factor (perhaps as much as 10 times) without damage or noticeable changes in linearity.

I. Spectral response

The *spectral response* defines how the *performance of a detector (responsivity or detectivity) varies with wavelength*. The spectral response is defined by curves such as shown in Figure 6-2, which presents generalized curves showing relative spectral response as a function of wavelength for photon detectors and thermal detectors. The exact shape of the spectral response and the numerical values depend on the detector type and the material from which the detector is fabricated. Many different types of detectors are available, with responses maximized in the ultraviolet, visible, or infrared spectral regions. Again, the manufacturer usually specifies the spectral response curve. One should choose a detector that responds well in the spectral region of importance for the particular application.

Conclusion: It is an advanced technology of transmitting information from one place to another by sending pulses of light through an optical fiber, in these technology optical detectors functions as demodulators at the receiver side. It provides good performance. Due to huge developments in semiconductor technologies, these detectors reduced to very small size, and available at low cost, so easily can maintained in the optical communications.

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