THEORY AND APPLICATION OF MAGNETO-OPTIC TECHNIQUES IN THE NON CONTACT MEASUREMENT OF CURRENT

Oleh

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ABSTRACT

Although the use of semiconductor magnetic sensors and fiber optical devices for making quantitative industrial controls, navigation systems, medical imaging and land-mine detection have been long established. There exists a body of other measurement capabilities for such devices, which have gone generally unnoticed. These involve measurement of current, charge carrier, magnetic flux, voltage and power which may be generally referred to as electrical quantities. The semiconductor magnetic sensors used to detect changes in current as big as 10.0A and on the other hand, the photo detector used to detects changes in light due to the variation of current as small as 1.0mA. Because of the measurement occurs contact less and a high temporal resolution is achievable, this sensor and optical techniques can open up a new perspectives in the field of real-time production metrology, for example controlling DC motor or a chemical process with saves in consuming time, manpower and money.

ABSTRAK

Kegunaan sensor magnetik semikonduktor dan peralatan gentian optik untuk membuat kawalan industri secara kuantitatif, sistem navigasi, gambaran dalam bidang perubatan dan pengesanan periuk api telah lama ditubuhkan. Walaubagaimanapun, satu bidang keboleukuran untuk alat tersebut wujud di mana secara umumnya tidak diketahui ramai. Ini melibatkan pengukuran arus, cas pembawa, fluks magnet, voltan dan kuasa yang umumnya dirujuk sebagai kuantiti-kuantiti elektrik. Sensor magnetik semikonduktor digunakan untuk mengesan arus tinggi seperti 10.0 ampere dan pengesan cahaya digunakan untuk megesan perubahan cahaya disebabkan oleh perubahan atau variasi arus yang sekecil 1.0milliampere. Disebabkan oleh pengukuran ini dapat dibuat tanpa sentuh dengan kabel elektik dan pada resolusi suhu tinggi, maka sensor dan teknik-teknik gentian optik ini boleh mewujudkan satu perspektif baru dalam bidang metrologi produksi semasa. Sebagai contohnya, kawalan motor DC atau kawalan proses kimia dapat dijalankan dengan cermat, cepat dan pada kos yang rendah.

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Chapter 1

INTRODUCTION

1.1 Introduction

The area of measurement is, of course, closely allied to that of laboratory teaching, and since this facet of engineering education is the subject of some controversy, there is certainly scope for a wide variety of approaches. One can consider the general field to be composed of two parts: the hardware of the measurement and techniques of experimentation. Being a result oriented application; it requires deep knowledge of hardware and patience in experimentation. Software based applications have made the real time measurement an extremely difficult job. However, real time measurement is always challenging and provides solutions to difficult problems. A contact less measurement of physical quantities is a challenging job and is successfully done in the case of temperature. However, we require performing it in the case of current, voltage and power especially in the case of measurement of D.C. current, voltage and power. In A.C. current-voltage, this job can be done by using current transformer, etc. However, it is very difficult to transfer direct current and direct voltage of high values. In this project, two techniques have been tried to measure high values of current.

Initially, LED is used to transfer optical power from one place to another through optical fiber. In this case knowledge of optical fibers, light sources and their practical handling will be required. In second case, famous Hall Effect devices are used to measure current without making real contact with the current and voltage under measurement.

Use of fiber optic devices for making quantitative light measurement and semiconductor magnetic sensor for position sensing has been long established. There exist, however, a myriad of measurement capabilities for such devices, which have gone generally unnoticed, and are widely misunderstood. We may loosely refer to this category of application as magneto-optical electrical quantities sensing. In this field, the measurement of current, voltage and power may fall into.

Contact sensors are requiring an electrical connection with signal conditioning electronics which can be awkward and dangerous in some applications. In addition, since the time required to make a measurement is shortened, and furthermore the electrical interface between the sensor and the device under test does not have to be considered. As a non-contact diagnostic, these devices can be used in situations where electrical connections and their supervision at the surface may be very difficult.

The most common application of magneto-optical sensors are in the field of industry, medicine, entertainment, remote sensing and analysis, basic research, instrumentation, image recording, inspection, military, optical data storage, telecommunications and etc. These devices are available with various sensitivities and dynamic ranges and can be fairly inexpensive. The basic theory of operation of each type, it's characteristic, advantages and disadvantages also have been discussed. The sensors outputs current or voltage signal directly proportional to the measured current, thereby providing current measuring and displaying capabilities to instruments with low current or voltage inputs. When making a measurement, the current carrying conductor is not broken and remains electrically isolated from the sensor terminals. It is not necessary to interrupt the power supply when using a current sensor or photo detector for taking measurements or repairs, so costly down time can be eliminated. In addition, all fiber optic construction enables flexible and small volume packaging formats.

1.2 Scope of the Project

Chapter II deals with the review of techniques for the measurement of physical quantities and focuses on sub-topics of contact and non-contact measurement of current, charge, voltage and power.

Chapter III deals with the theory and application of optical techniques for the measurement of electrical quantities and focuses on sub-topics of transmitter (LED), photo detector, optical fiber, interconnection devices connectors and their application in everyday use.

Chapter IV deals with the theory and application of magnetic techniques in the measurement of electrical quantities and focuses on sub-topics of technologies used for measuring current, Hall Effect, Lorentz Force, accuracy characteristics and dynamic response of sensor, measurement of Hall Effect in laboratory and application of Hall Effect in modern day use.

Chapter V deals with all the experimental methods and the results obtain with optical techniques and magnetic sensor techniques. The discussion from the laboratory work and the conclusion are also discussed.

The analysis presented in this study is based on information derived from professional journals, technical literature, specific information and catalogs, and on-line sources. This paper contains additional information including specific products and devices, applications, as well as future trends and developments.

Chapter 2

REVIEW OF TECHNIQUES FOR THE MEASUREMENT OF PHYSICAL QUANTITIES

2.1 Contact and Non-Contact

Inspection system (contact and non-contact) is very important due to the growing trend toward miniaturization, especially in the computer, medical device, electronics industries, resurgence of selective assembly and match-fitting practices. By their nature, smaller parts of a product are often more prone to damage, deformation or contamination by even slight contact with a probe. Another factor is that current sampling rates often run higher than they once did, creating the need for higher inspection speed. Non-contact inspection system solves these problems and overall impact of these trends is that current non-contact systems are handling about 40 percent of the inspection workload, and this number still increases nowadays. The stakes in choosing the right inspection system for particular operation include measurement throughput, repeatability, accuracy, cost, process control and traceability, operational simplification, part quality and ease of documentation.

Most manufacturing quality assurance departments require measurement uncertainty to be quantified separately from the manufacturing process as well as from the measuring process itself. To reduce this uncertainty, we need instruments with speed, precision and excellent statistical software to facilitate tight, accurate gage reproducibility and reliability (gage R&R) studies. The most common part-inspection methods today include contact and non-contact instruments, such as sensors, coordinate measuring machines, microscopes and machine vision systems.

Non-contact systems are definitely faster than mechanical systems, particularly for high sampling rates (e.g. dozens of features or multiple axes). Therefore, we can measure more points, see patterns at once and measure in three axes in a single setup. Contact mechanical devices must traverse the part point-to-point, which can slow things down. Non-contact systems measure with absolutely no contact or probing. They are therefore ideal for measuring soft, deformable, sensitive work pieces, surgical instruments or safe handling of hazardous.

Process control simplification and quality are important in any competitive business today. The trend toward smaller, lighter, simpler products is forcing more manufacturers than ever to deal with parts too fragile to measure with conventional contact, mechanical equipment. In such cases, inspection requires systems that accommodate the parts, yet provide the necessary accuracy and cycle time. Non-contact inspection may be key to unlock our throughput, cost and quality challenges. Non-contact measurement devices are based on various technologies, including electric field, electromagnetic field, and light/laser. Figure 2.1 show a simple non-contact current measurement with a clamp-current probe.

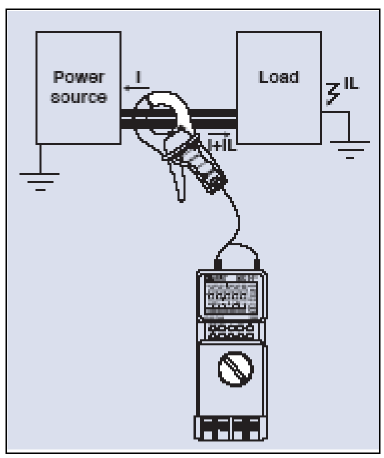


Figure2.1: Non-contact current measurement with clamp-on current probes

2.2 Historical Profiles

Before going on the techniques for measurement of physical quantities, it's more better we gain knowledge of the great scientists who are behind the invention of voltage, current and resistor.

2.2.1 Alessandro Antonio Volta (1745-1827)

An Italian physicist invented the electric battery which provided the first continuous flow of electricity and the capacitor. Born into a noble family in Como, Italy Volta was performing electrical experiments at age 18. In 1796, he was invention the battery which revolutioned the use of electricity. The publication of his work in 1800 marked the beginning of electric circuit theory. Volta received many honors during his lifetime. The unit of voltage or potential difference, the volt, was named in his honor.

2.2.2 Andre-Marie Ampere (1775-1836)

A French mathematician and physicist laid the foundation of electrodynamics. He defines the electric current and developed a way to measure it in the 1820s. Ampere born in Lyons, France and at age of 12 he mastered Latin in a few weeks, as he was intensely interested in mathematics and many of the best mathematical works ware in Latin. He was a brilliant scientists and a profile writer. He formulated the laws of electromagnetic, invented the electromagnetic the ammeter. The unit of electric current, the ampere, was named after him.

2.2.3 George Simon Ohm (1787-1854)

A German physicist, in 1826 experimentally shows the most basic law relating voltage and current for a resistor. Ohm's work was initially denied by critics. Born of humble beginnings in Erlanger, Bavaria, Ohm threw himself into electrical research. His efforts resulted in his famous law. He was awarded the Copley Medal in 1841 by the Royal Society of London. In 1849, he was given the Professor of Physics Chair by the University of Munich. To honor him, the unit of resistance was named after him.

2.3 Physical Quantities

2.3.1 Charge and Current

The most basic quantity in an electric circuit is the electric charge. Charge is an electrical property of the atomic particles of which matter consists, measured in Coulombs (C). An atom consists of electrons, protons and neutrons. The charge on an electron is negative and equal in magnitude to 1.602 X 10^{-19}C, while a proton carriers a positive charge of the same magnitude as the electron. The law of conversation of charge states that charge can neither be created nor destroyed, but only transferred. Whenever a conducting wire is connected to a battery, the charges are compelled to move; positive charges in one direction while negative charges move in the opposite direction. This motion of charges creates electric current as shown in Figure 2.2.

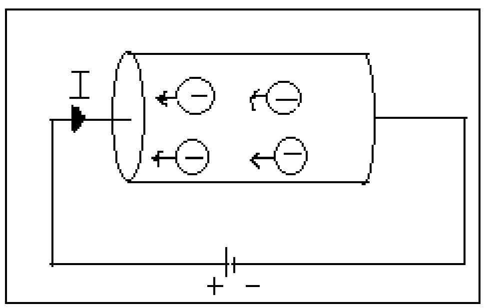


Figure2.2: Flow of electronic charge in a conductor

Electric current is the time rate of change of charge, measured in amperes (A).

$$i = \frac{dq}{dt} \qquad (2.1)$$

Therefore, current need not be a constant-value function. The two common type of current are dc and ac and their waveform shown in Figure 2.3.

i) if the current does not change with time, but remains constant, it is called as direct current (dc). A dc symbolize as I.

ii) the time-varying current called as sinusoidal current/ alternating current (ac) and represented by the symbol i.

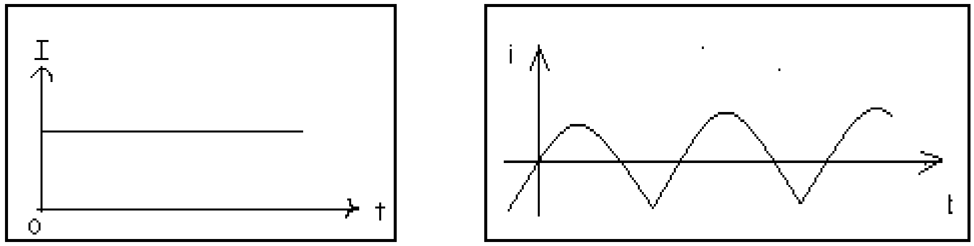


Figure 2.3: dc and ac graph

2.3.2 Voltage

Some work or energy transfer need to move electron in a conductor in a particular direction. This work is performed by an external electromotive force (emf) which also known as voltage or potential difference as shown in Figure 2.4. The voltage V_{ab} between two points a and b in an electric circuit is the energy or work need to move a unit charge from a to b.

$$V_{ab} = \frac{dw}{dq} \tag{2.2}$$

Therefore, voltage or potential difference is the energy required to move a unit charge through an element, measured in volts (V).

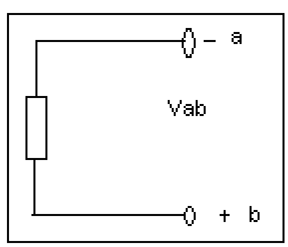


Figure 2.4*:* Polarity of voltage V_{ab}

A constant voltage called as dc voltage and represented by V. a dc voltage commonly produced by a battery. A sinusoidally time-varying voltage is called an ac voltage is represented by v. An ac voltage is produced by an electric generator.

Difference between current and voltage:

(i) Electric current- always through an element

(ii) Electric voltage- always across the element/ between two points

2.3.3 Resistance

Material in general has a characteristic behavior of resisting the flow of electric charge which known as resistance and represented by the symbol R. The resistance of any material with a uniform cross-sectional area A depends on A and its length, l as shown in figure 2.5.

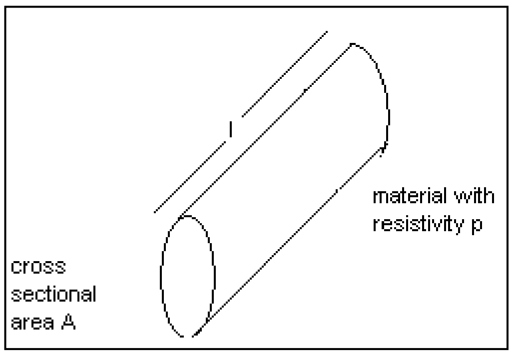


Figure 2.5: Resistor

$$R = \rho \frac{l}{A} \tag{2.3}$$

ρ - resistivity of materials (ohms-meters)

Resistor is a circuit element which used to model the current-resisting behavior of a material. Generally, metallic alloys and carbon compounds used to make resistors for the purpose of constructing circuits. Figure 2.6 show the circuit symbol for the resistor.

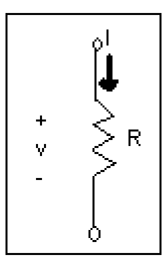


Figure 2.6: circuit symbol for resistance

Ohm's Law is a relationship used between current and voltage for a resistor. Ohm's Law states that the voltage, v across a resistor is directly proportional to the current, i flowing through the resistor.

$$v \ \alpha \ I \tag{2.4}$$

Ohms defined the constant of proportionality for a resistor to be the resistance, R. Whenever the internal or external conditions of an element altered (e.g. changes in temperature), the resistance will be changed.

$$V = iR \tag{2.5}$$

The resistance R of an element denotes its ability to resist the flow of electric current and it is measured in Ohms (Ω).

$$R = \frac{v}{i} \tag{2.6}$$

To apply Ohm's law, the current, i direction and voltage, v polarity should conform to the passive sign convention as in figure 2.6. The value of R can be range from zero to infinity. The two extreme possible values of R are:

i) R = 0 (short circuit = a circuit element with resistance approaching zero)

ii) R = ∞ (open circuit = a circuit element with resistance approaching infinity)

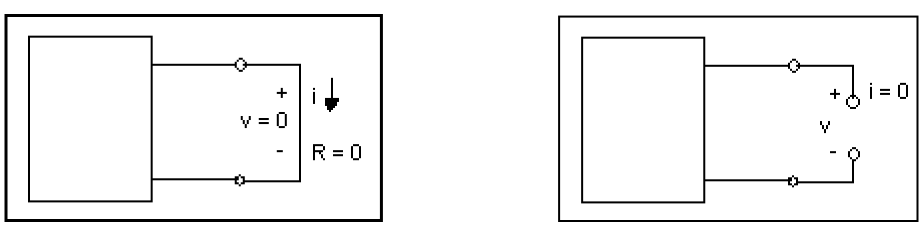
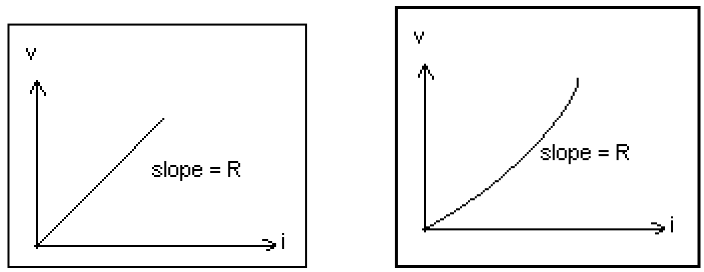


Figure 2.7: Short circuit and open circuit

Not all resistors obey Ohm's law. A resistor that obeys Ohm's law is knows as a linear resistor and nonlinear resistor does not obey Ohm's law. Figure 2.8 show this two types of resistors where graph (a) is a linear resistor with straight line passing through the origin and graph (b) is nonlinear resistance varies with current (e.g. Light bulb and diode)



(a) (b)

Figure 2.8: Voltage versus current graph

The power dissipated by a resistor can be expressed in terms of R:

$$P = vi = i^2R = v^2/R \tag{2.7}$$

The power dissipated in a resistor is a nonlinear function of either current or voltage. The power dissipated in a resistor is always positive. Therefore, a resistor always absorbs power from the circuit and incapable of generating energy.

2.3.4 Power and Energy

Power is the time rate of expanding or absorbing energy, measured in watts (W).

$$P = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi \qquad (2.8)$$

The power, P in eq(2.9) is a time-varying quantity and is called instantaneous power. Therefore, the power absorbed or supplied by an element is the product of the voltage across the element and the current through it.

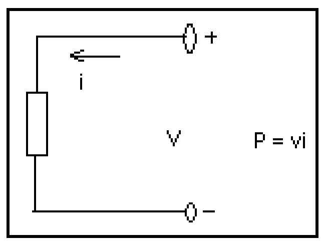


Figure 2.9: Power Measurement

The law of conversation of energy said that the algebraic sum of power in a circuit at any instant of time must be zero.

$$\Sigma P = 0 \qquad (2.9)$$

thus, the total power supplied to the circuit must balance the total power absorbed. For a ac circuit the instantaneous power absorbed is:

$$P(t) = v(t).i(t)$$

$$= V_m I_m \cos(wt + \theta_v)\cos(wt + \theta_i) \qquad (2.10)$$

the average power absorbed by a resistor R:

$$P = I^2_{rms}R = V^2_{rms}/R \qquad (2.11)$$

$$\text{Power factor: } pf = \cos(\theta_v - \theta_i) \qquad (2.12)$$

Generally, there are three types of power:

i) True Power (P)- Power dissipated by a load, symbolized by P and is measured in the unit of Watts (W).

ii) Reactive Power (Q)- Power merely absorbed and returned in load due to its reactive properties, symbolized by Q and is measured in the unit of Volt-Amps-Reactive (VAR).

iii) Apparent Power (S)- Total power in an AC circuit, both dissipated and absorbed/ returned, symbolized by the letter S and is measured in the unit of Volt-Amps (VA).

$$P = I^2R = \frac{E^2}{R} \text{ Watts} \tag{2.13}$$

$$Q = I^2X = \frac{E^2}{X} \text{ Volt-Amps-Reactive (VAR)} \tag{2.14}$$

$$S = I^2Z = \frac{E^2}{Z} = IE \text{ Volt-Amps (VA)} \tag{2.15}$$

$$S^2 = Q^2 + P^2 \tag{2.16}$$

Chapter 3

THEORY AND APPLICATION OF OPTICAL TECHNIQUES FOR THE MEASUREMENT OF ELECTRICAL QUANTITIES

3.1 History of Fiber Optic Technology

Fiber optic systems holds many advantages over conventional copper wire and coax cable systems, including EMI immunity, lighter weight, higher bandwidth, lower cost and better signal quality. Fiber optic components transmit information by turning electronic signals into light and light signals back into electronic signals. The three basic elements of a fiber optic link are transmitter (LED), receiver (photo detector) and optical fiber. History of invention and development of optical fiber from year 1870 until today are summarizing as in Table 3.1 below.

Table 3.1: History of fiber optic technology

year	occurrence
1870	John Tyndall demonstrated that light used internal reflection to follow a specific path
1880	William Wheeling patented his method of light transfer piping light
1880	Alexander Graham Bell developed photo phone, the world's first optical AM audio link
1950's	Narinder Kapany and Brian O'Brian developed fiberscope, which used the first practical glass-coated fiber
1956	Narinder Kapany coined the term fiber optics
1960's	The laser gained acceptance in scientific circles
1966	Charles Kao and Charles Hockam proposed that optical fiber could carry laser signals
1977	AT&T and GTE installed the fiber optic telephone system
1980	First fiber optic video transmission took place during Winter Olympics in Lake Placid, New York
1994	First fiber optic digital video transmission took place during Winter Olympics in Lillehammer, Norway
1998	A Bell Lab's group broke the terabit per second barrier when they successfully transmitted 100 simultaneous 10Gb/s signals on one fiber over a distance of 400km using DWDM technology.
2000	Broadband networks offering interactive communication services have become commonplace.
2005	All-optical networks may be the next generation solution to increasing bandwidth demands as a result of the growth of the internet

3.2 Fiber Optic Components

Basic elements of a fiber optic link are transmitter (LED), receiver (photo detector), optical fiber and connector. These elements characteristics, advantages and their operation are explained as below.

3.2.1 Optical Fiber

Optical fibers are extremely thin strands of ultra-pure glass designed to transmit light signals from a transmitter to a receiver. These signals represent electrical signals that include, in any combination, video, audio, or data information. Figure 3.1 shows the general cross-section of an optical fiber and their characteristics are tabled in Table 3.1 as below.

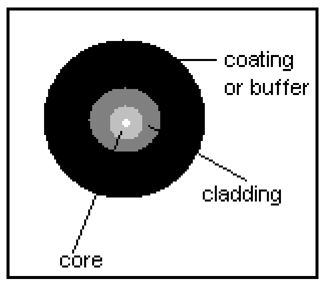


Figure 3.1: Cross-section of an Optical Fiber

Table 3.2: Cross-sections characteristics

	region	characteristics
core	Center	Carries light, its diameter range 9 μm to 100 μm, doped glass materials
cladding	Surround the core	Confines light in the core, typical diameter 125 μm, refractive index of cladding less than refractive index of core, doped glass materials
Coating/ buffer	outer	A plastics material, provides protection and preserves strength of glass fiber, typical diameters are 250 μm, 500 μm, 900 μm.

Fiber optic cable requires proper handling. The basic guidelines in addition to manufacturers specifications should follow for a good cable maintenance:

(a) Do not stretch, puncture, or crush the fiber cables with staples, heavy equipment, doors, etc.

(b) Always maintain the minimum bend radii specified by the cable manufacturer. The minimum bend radii is usually 10-20 times a cable's outer diameter.

(c) Keep the dust caps on the cable ends, transmitter and receiver until make the connections. Dust covers put back on when the cable is disconnected.

(d) Do not polish the connectors with a cloth made of synthetic fibers, as this will charge up the fiber and attract dust.

3.2.1.1 Testing and Measurement Techniques

Fiber optic systems may undergo functional testing or performance testing. Test equipment for fiber optic systems include an optical power meter, optical light source, optical loss meter, fiber identifier, talk set, optical time domain reflector meter, optical spectrum analyzer, optical attenuator, back reflection meter, and local injector detectors. Automated switching systems for testing components such as cable, connectors, or couplers are beneficial in keeping down the cost of test equipment. Center wavelength and spectral width can be measured with an optical spectrum analyzer. Detector bandwidth can be measured by exciting the detector with a sine wave-modulated laser source.

3.2.1.2 Principles and operation

The principle of total internal reflection governs the operation of optical fiber. The basis for optical fiber operation determined by Snell Law as in total reflection the angle of incidence is equal to the angle of reflection.

$$\text{Snell Law: } \theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) \tag{3.1}$$

speed of light travels in fiber:

$$v = \frac{c}{n} \tag{3.2}$$

NA(numerical aperture)- describes the light gathering capability of fiber.

$$NA = \sin\alpha = \sqrt{n_1^2 - n_2^2} \tag{3.3}$$

$$\alpha = \sin^{-1}\sqrt{n_1^2 - n_2^2} \tag{3.4}$$

propagation time through a fiber:

$$t = \frac{Ln}{c} \tag{3.5}$$

n_1 - refractive index of the core, n_2 - refractive index of the cladding

c - speed of light = 2.998 X $10^8 ms^{-1}$, n = refractive index = 1.47

α - imaginary cone of acceptance, L = fiber length in meters

For a given application, choose of optical fiber depend on its size, material, attenuation, bandwidth-distance product and amount of power can be coupled to the fiber. A discussion of the decibel is necessary to understand these link loss values. The decibel (dB) is a convenient means of comparing two powers. It is always a ratio between two numbers. For fiber optics, the ratio is usually the transmitter output power compared to the receiver input power. The equation to calculate a decibel is:

$$\text{dB} = 10 \text{ X } \log_{10}\left(\frac{power_1}{power_2}\right) \tag{3.6}$$

Extinction ratio is a ratio of the low or OFF optical power level (P_L) to the high or ON optical power level (P_H).

$$\text{Extinction ratio (\%)} = \left(\frac{P_L}{P_H}\right) \text{ X } 100\% \tag{3.7}$$

3.2.2 Light Emitters

Light emitters convert electrical signal into a corresponding light signal that can be injected into the fiber. A light emitting diode (LED) is a semiconductor p-n junction that is optimized to release light of approximately the band gap energy under forward bias, when electrons fall from the conduction band to the valence band. The electrons and holes migrate toward the junction where they recombine and release light whose energy corresponds to the band gap energy. LED's are used as visible indicators in most electronics equipment and laser diodes are most widely used in compact disks and DVD players. Laser and LED's operate on the same basic principle, the principle of the p-n semiconductor junction found in transistors and diodes. Table 3.3 compares the major characteristics between LED and laser diode, Figure 3.2 shows the sources and emission patterns and Figure 3.3 shows the typical package of LED's . Whenever making decision to use whether LED's or LD's in fiber optic systems is depend on:

i) center wavelength

ii) spectral width

iii) optical output power of the light source

Table 3.3: Difference between LED and Laser Diode

Parameter	Light-Emitting Diode	Lased Diode
Output power	Linearly proportional to drive current	Proportional to current above the threshold
Current	Drive current: 50 to 100 mA peak	Threshold current: 5 to 40 mA
Coupled power	moderate	high
bandwidth	moderate	High
Wavelength available	0.66 to 1.65 μm	0.78 to 1.65 μm
Emission spectrum	40nm to 190nm FWHM	0.01pm to 10nm FHWM
Cost	$5 to $300	$5 to $3000

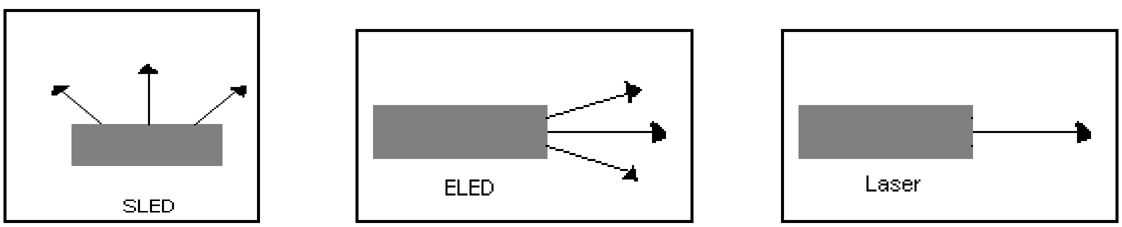


Figure 3.2: Sources and Emission patterns

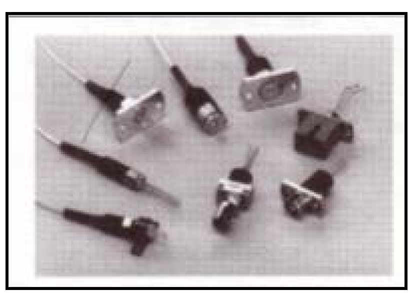
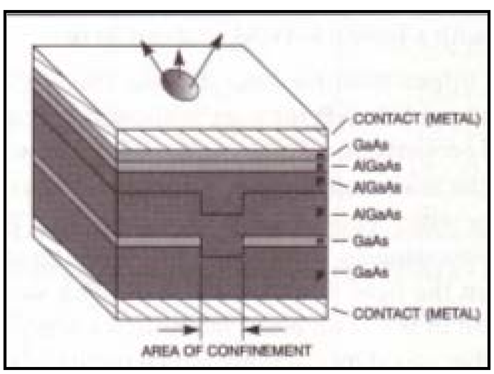


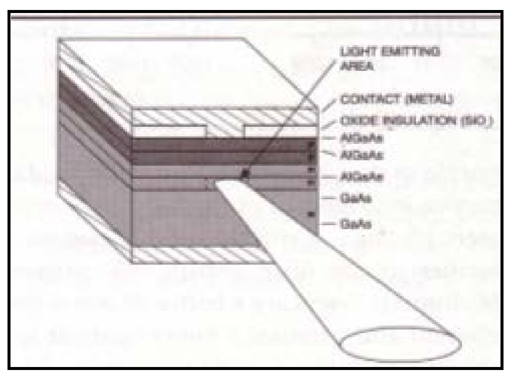
Figure 3.3: typical packaged LED's

The best results are usually achieved by coupling as much of a source's power into the fiber as possible. The key requirement is that the output power of the source is strong enough to provide sufficient power to the detector at the receiving end considering fiber attenuation, coupling losses and other system constrains. The two types of light sources used in fiber optics are light-emitting diodes (LED's) and laser diodes (LD's). The three common type of light emitter sources are summarized in Table 3.4 their material shown in Figure 3.4.

Table 3.4: Compare of SLED, ELED and Laser diode.

surface-emitting LED (SLED)	Emits light over a very wide angle, therefore it is difficult to focus more than a small amount of the total light output into the fiber core. Often called as Lambertian emitter because of the nature of the emission pattern, this broad emission angle is attractive for use as an indicating LED because of the wide viewing angle, but is a detriment for fiber optic uses. It is low cost, dominant type in use.
edge-emitting LED (ELED)	Has much narrower angle of light emission and smaller emitting area, allows a larger percentage of total light output to be focused into the fiber core. Faster than SLED, very temperature sensitive.
Laser diode	Has a very narrow emission angle, emitting spot very small, a very high percentage of output light can be focused into the fiber core and fastest than SLED and ELED.





SLED ELED

Figure 3.4: SLED and ELED material

LEDs commonly classified according to their colors and wavelength as shown in Table 3.5.

Table 3.5: Light Emitting Diode Color Variations

Colors	Wavelength (nm)	Semiconductor Composition
Infrared	880	GaAlAs/GaAs
Ultra Red	660	GaAlAs/GaAlAs
Super Red	633	AlGaInP
Super Orange	612	AlGaInP
Orange	605	GaAsP/GaP
Yellow	585	GaAsP/GaP
Pure Green	555	GaP
Super Blue	470	GaN/SiC
Blue Violet	430	GaN/SiC
Ultraviolet	395	InGaN/Sic

The LED's optical power drops as the temperature increases. Temperature also affects the peak emission wavelength. Most LED's exhibit a 0.3nm/^{0}C to 0.6nm/^{0}C drift in the peak emission wavelength as temperature varies as shown in Figure 3.5. This is important in multi-wavelength systems where there is a possibility of crosstalk, the interference of one channel on another, if the LED wavelength drifts.

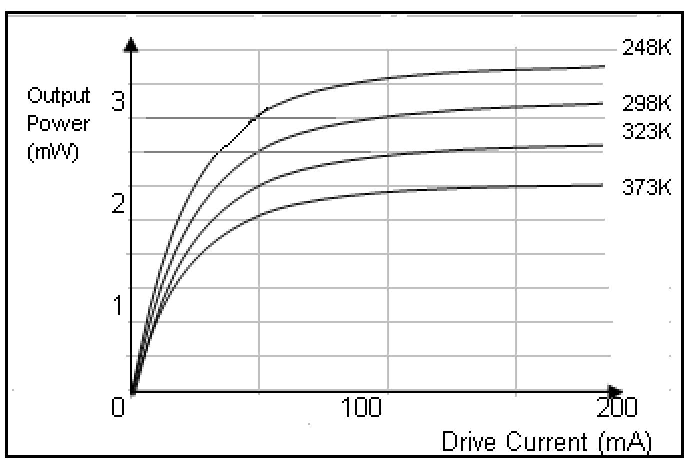


Figure 3.5: Typical LED Behavior versus Temperature

LED optical output is approximately proportional to drive current. Temperature also affects the optical output. Figure 3.6 shows typical behavior of an LED at 0.1% and 100% duty cycle. The drop is primarily due to the heating of the LED chip. Most LED's have light versus current curves that droop or fall below a linear curve.

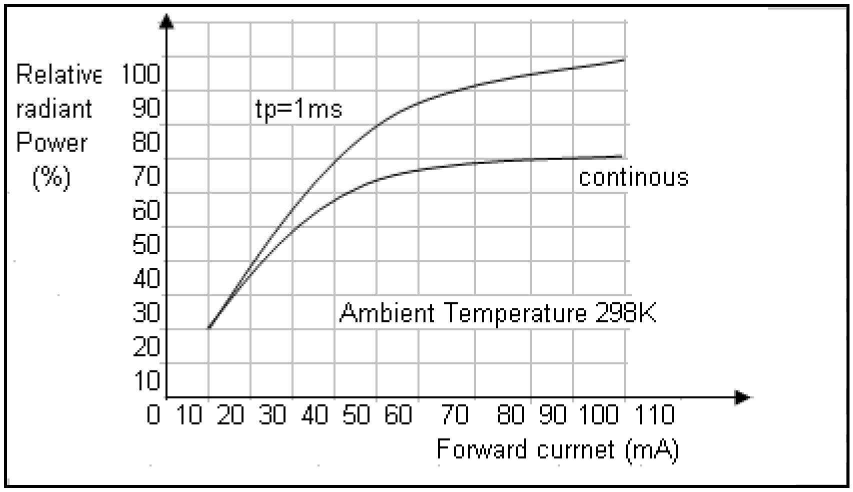


Figure 3.6: optical Output versus Current in an InGaAsP LED

But the ideal light output against current characteristics for an LED is shown in Figure 3.7. It is linear corresponding to the linear part of the injection laser optical power output characteristics before lasing occurs. Intrinsically the LED is a very linear device in comparison with the majority of injection lasers and hence it tends to be more suitable for analog transmission where severe constrains are put on the linearity of the optical source. However, in practice LED's do exhibit significant nonlinearities which depend upon the configuration utilized. It is therefore often necessary to use some form of linearizing circuit technique (e.g. predistortion linearization or negative feedback) in order to ensure the linear performance of the device to allow its use in high quality analog transmission systems.

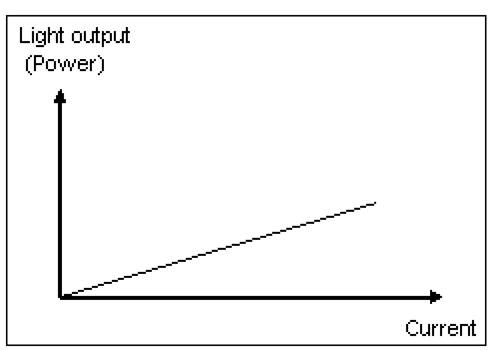
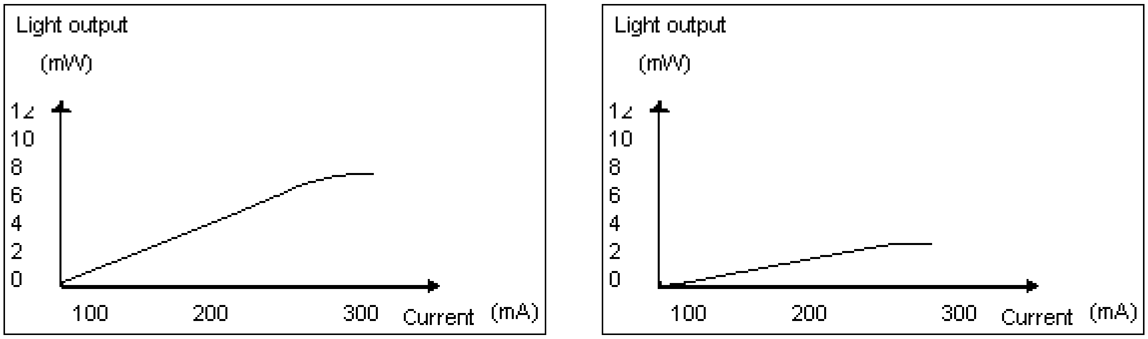


Figure 3.7: Ideal light output vs current

Figure 3.8 at below show the light output against current characteristics for typically SLED and ELED. It may note that the SLED radiates significantly more optical power into air than the ELED and that both devices are reasonably linear at moderate drive currents.



SLED ELED

Figure 3.8: Light output power vs d.c. drive current

Figure 3.9 show the factor of temperature over three major LED structures. To utilize the high power potential of such devices at elevated temperatures, the use of thermoelectric coolers may be necessary.

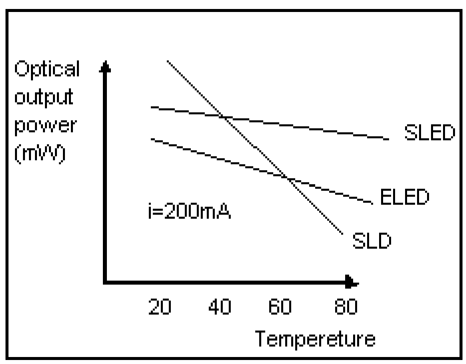
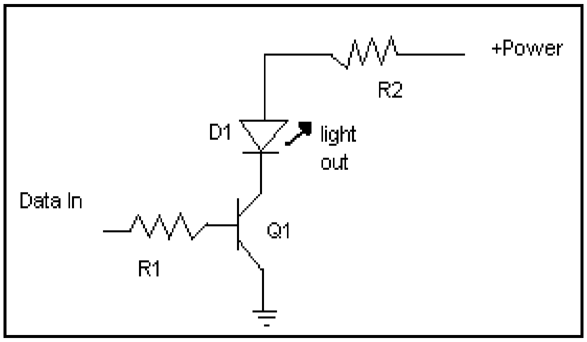
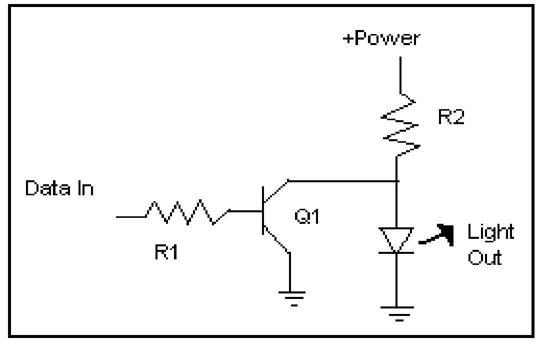


Figure 3.9: Power versus temperature for ideal LED

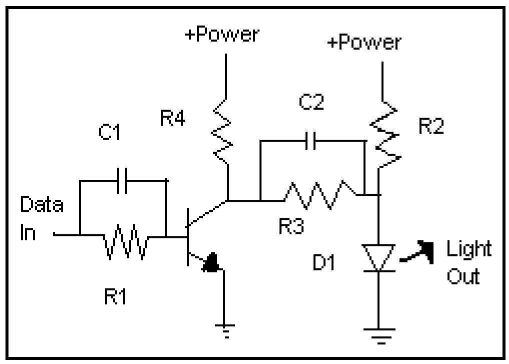
LED's are usually driven either a digital signal or an analog signal. Figure 3.10 show the three popular digital LED driver circuits.



Series



Shunt



Faster

Figure 3.10: LED Driver Circuit

Series: with Q1 in the off condition, no current will floe through the LED, and no light will be emitted. Whenever transistor q1 is on, the cathode (bottom) of the LED will be pulled low. Transistor Q1 will pull its collector down to about 0.25 Volts. The current is equal to the voltage across resistor R2 divided by the resistance R2. The voltage across R2 is equal to the power supply voltage less the LED forward voltage drop and the saturation voltage of the drive transistor. This circuit offers the key advantage of a low average power supply current.

Shunt: resistor R2 provides a positive current to turn on the LED. R2 would be around 40Ω and transistor Q1 provides turn-on current about 100mA peak. When saturated, transistor Q1 will have an impedance of a few Ohms. This provides a much larger discharging current allowing the LED to turn off quickly. Power dissipation typically more than doubles in a shunt driver circuit compared to the series driver. In fact, the circuit draws more current and power when the LED is off than when the LED is on.

Faster: capacitor C1 improves the turn-on and turn-off characteristics of transistor Q1 itself. Resistors R3 and R4, and capacitor C2 provide overdrive when the LED is turned on and under drive when the transistor is turned off. The overdrive and under drive activities accelerate the LED transistors.

Whenever turned on, the LED will have a forward voltage drop of about 1.1 to 1.5 Volts. Shorter wavelength diodes (e.g. 850 nm) have the largest voltage drops. As the wavelength increases, the voltage drop decreases. This phenomenon can be related to the bandgap energy E_g of the LED. Equation 1 defines the bandgap energy E_g:

$$E_g = hc/\lambda = 1240\text{eV-nm}/\lambda \qquad (3.8)$$

h = Plank's Constant = 4.13 x 10^{-15} eV•s , c = speed of light, λ = wavelength in nm

Whenever using a LED in an electrical circuit, the supply voltage is not extremely important. The most important thing is the current flow through the LED. The current through the diode must be limited by a series resistor. An LED has a specified maximum continuous current rating. Most LEDs can pass up to 20mA continuously without damage but it is not necessary to use the maximum rated current. An LED will light with much less current. The difference between high current and low current will be the brightness of the LED. Knowing the voltage drop of the LED and the saturation voltage of the transistor we can compute the LED current. Equation 2 below shows the general form of the calculation.

$$I_{LED} = \frac{V_{POWER} - V_{LED} - V_{SAT}}{R} \qquad (3.9)$$

V_{POWER} = supply voltage, V_{LED} = forward voltage of LED, V_{SAT} = drive transistor saturation voltage, R = series LED current limiting resistor, I_{LED} = LED peak current