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Implementation of Fiber Optic Communication System Using Developed Computer Program

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Abstract: *Fiber optic systems have recently received a great deal of attention and they are used now as a preferred transmission medium in current communication systems because they offer great information carrying capacity over longer repeater less distances at costs lower than conventional copper-wire system. Any fiber optic communication system consists of three parts, transmitter, fiber optic cable and receiver. In this paper each part is implemented into computer program. Also in this paper we have discussed the recent developments in the field of fiber optic communications.*
Keywords: *Fiber optic, Transmitter, Receiver.*

I. Introduction

The ever increasing demand for communication services requires communication systems of large information carrying capacities and because of the inherent potentialof enormous bandwidth offered by light work began for a means of make use of light-waves for communication purposes.
A great interest in communication at the optical frequencies was created in 1960 with the advent of the laser, which made available a coherent optical source. Since optical frequencies are on the order of 5 x 10^{14} Hz (see Figure 1), the laser has a theoretical information capacity exceeding, that of microwave systems by a factor of 10^5, that is approximately equal to 10 million TV channels [1].

With the potential of such wide-band transmission capabilities in mind, a number of experiments using atmospheric optical channels were carried out in the early 1960s. These experiments showed the feasibility of modulating a coherent optical carrier wave at very high frequencies. However the high installation expense that would be required, the tremendous costs that would be incurred to develop all necessary components, and the limitations imposed on the atmospheric channel by rain, fog, snow, and dust make such extremely high-speed systems economically unattractive in view of present demands for communication channel capacity. Nevertheless, numerous developments of free space optical channel systems operating at base-band frequencies are in progress for earth to space communications. Concurrent with the work on atmospheric optical channels were the investigations of optical fibers, since they can provide a much more reliable and versatile optical channel than the atmosphere. Initially, the extremely large losses of more than 1000 dB/km observed in the best optical fibers made them appear impractical. In 1970 Kapron.Keck.andMarurer of the Coming Glass Works fabricated a fiber having 20-dB/km attenuation proving that the high losses were a result of impurities in the fiber material [2].

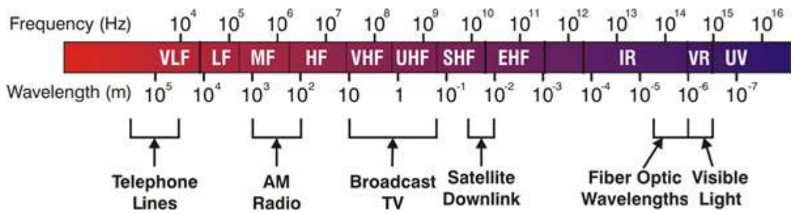


Figure 1. Electromagnetic Spectrum.

The first generation of optical fiber links operated in the 0.8-0.9 μm wavelength band, since in this region the fibers made at that time exhibited a local minimum in the attenuation curve, and optical sources and photo-detectors operating at these wavelengths were available. Later, fiber manufactures became able to fabricate optical wave-guides with very low losses at the 1.1 to 1.6 μm region by reducing the concentrations of the hydroxyl ions and metallic ion impurities in the fiber material. This spectral bandwidth is usually referred to as the long-wavelength region. Increased interest thus developed at 1.3 μm wavelength since this is the region of minimum signal distortion in pure silica. Further development and research are in progress to realize the use of new types of fiber at 3 to 5 μm wavelength band which expected to have attenuations ofless than 0.01 dB/km.

Communication using an optical carrier wave guided using a glass fiber has a number of extremely attractive features:

1. Extremely wide system bandwidth.
2. Small size and weight.
3. Immunity to electromagnetic interference and crosstalk.
4. Signal security.
5. Low signal attenuation.
6. Unlimited resources.
7. Low cost.
8. Safety.

From the above-mentioned features of using optical fiber link as a transmitted media, it is proven that it is the best communication link. The following sections review the different components that constitute the optical fiber communication system, namely the optical transmitter,the optical fiber links and the optical receiver.

II. Fiber Optic Communication System

Anyfiber optic communication system consists of three components: Transmitter,Fiber-optic Cable, and Receiver as illustrated in Figure 2.

The optical transmitter converts the electrical input signal, representing the information to be transmitted, into an optical signal by modulating the output of the optical source using one of two methods; by varying the source drive current or by varying the light intensity at the output of the light source. The fiber-optic cable is now responsible to carry this light signal to the receiver end which in turn demodulate this light signal into its original transmitted form [3].

Fiber optic system is almost configured to accept signals in a digital form,because the numerous advantages offered by using digital techniques over analog techniques.

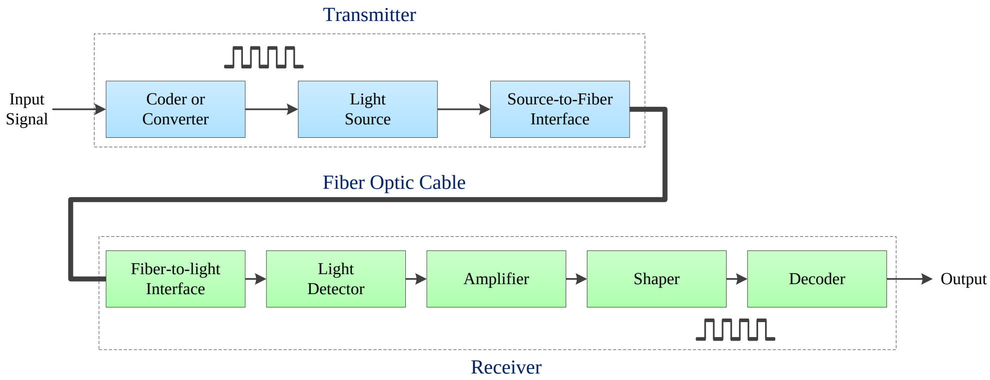


Figure 2. Fiber optic communication system

III. Optical Transmitter

The transmitter converts the input electric signal into an optical signal. As shown in Figure 2 transmitter consists of coder or converter, light source and sourceto fiber interface. The information at input is converted into digital signals by coder or converter circuit (analog to digital converter (ADC)).Depend on digital pulse light source turns ON/OFF very rapidly, in this way digital pulse is converted to equivalent light pulse. Source to fiber interface is a mechanical interface to couple the light source into the fiber optic cable [4].

A suitable source for an optical communications system must meet certain specifications such as, emission at certain wavelength at which fiber has low transmission loss, ease of modulation, sufficient ruggedness, efficient conversion of prime power to light coupled into the fiber, ease of coupling the source output to the fiber, and other more subtle requirements.

Nowadays, two optical sources meet most of the requirements listed above. These are the semiconductor light-emitting diode (LED) and the semiconductor injection laser diode (ILD). The LED and IDL are both solid state semiconductor devices, which can be fabricated from various semiconductor material systems, which allows the device designer to select the designed wavelength of emission. The devices fabricated in the gallium aluminum arsenide material system can emit in the range of wavelengths between 0.8 to 0.9 μm while devices fabricated in the indium gallium arsenide phosphide material system can emit in the range of wavelengths between 1.0 and 1.6 μm. Both LED's and IDL's can be modulated by varying the electrical current used to power the devices (direct modulation). LED's can achieve a direct modulation rate of 20 MHz to beyond 1 GHz (depending on the materials, the device design, and tradeoffs against other parameters), while

IDL' s can achieve a rate of 5 to 10 GHz. The spectral width of an LED is relatively large, which limits its range of applications. The spectral width of a laser can be very small (a single frequency of emission) depending upon the device design.

3.1LED and Laser Performance Comparison

The Lasers and LEDs have similar operating wavelengths; therefore, matching wavelength to waveguide is similar for both devices. Drive currents are not similar; lasers require bias currents and large peak currents as compared to LEDs. One of the most important parameters is spectral width; LEDs exhibit a magnitude larger figure. Beam-widths of lasers are very small compared to LEDs, and power output is high; therefore, laser power density is very high [4].

The large bandwidth is a big advantage of lasers over LEDs. Lasers have at least one magnitude greater bandwidth [4]. LEDs are useful for short-range communications where the distance is less than 10km. They have useful bandwidth of 250 MHz.

Another important advantage of lasers over LEDs is that, lasers have much moreoutput power than LEDs; they launch about 50 to 200 more power into the waveguide and about 40% or greater if the source area of the LED is greater than the fiber, which is the usual case.

In the other side, laser sources have some disadvantages compared to the LEDs source. One of the greatest disadvantages of lasers is the temperature effect. Such effects become a serious problem for some application such as military applications.

Construction techniques for heterojunction lasers are the same as for LEDs with the exception to tighter tolerance requirements. The high performance of lasers is due tothese requirements. These factors affect cost; therefore, a cost-performance trade-off exists.

The lifetime of LEDs is about a magnitude greater than that of lasers. Lasers exhibit more effects that will cause failure, such as crystal strain and cavity problem.

3.2Optical Transmitter Design

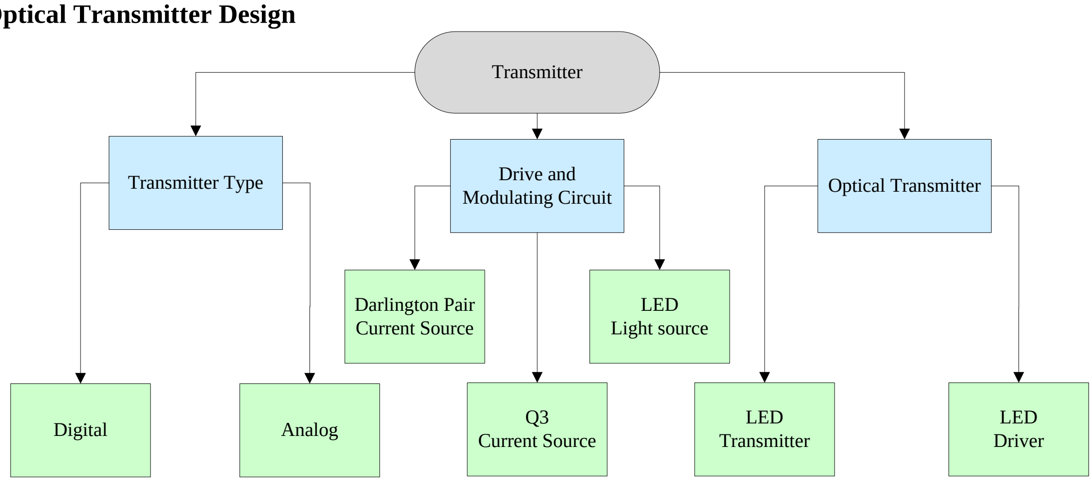


Figure 3. General Flowchart of the Fiber Optics System Transmitter

The transmitter design passes through three stages as shown above in Figure 3. The first stage is to define the type of the transmitter either analog or digital as well as choosing the right specification, which meets the output requirements such as risetime, bit rate, and output power. The program implementing this stage allows the designer to enter the transmitter data or call it from the database.

The second stage of transmitter design is to analyze the drive and modulating circuit of the light source. In fact there are more than one drive and modulating circuit for both laser and LED sources. But, in this program, only one circuit for LED light source is chosen to be analyzed; see Figure 4. Other circuits are somehow similar to one we have analyzed here. Laser light source drive and modulating circuits are more complex because the temperature dependence of laser threshold and higher modulation speeds; at which lasers are typically used.

The third stage of transmitter design is to analyze the LED transmitter and LED drives circuits. The program provides the ability to analyze two chosen circuits as shown in Figure 5 and Figure 6 respectively.

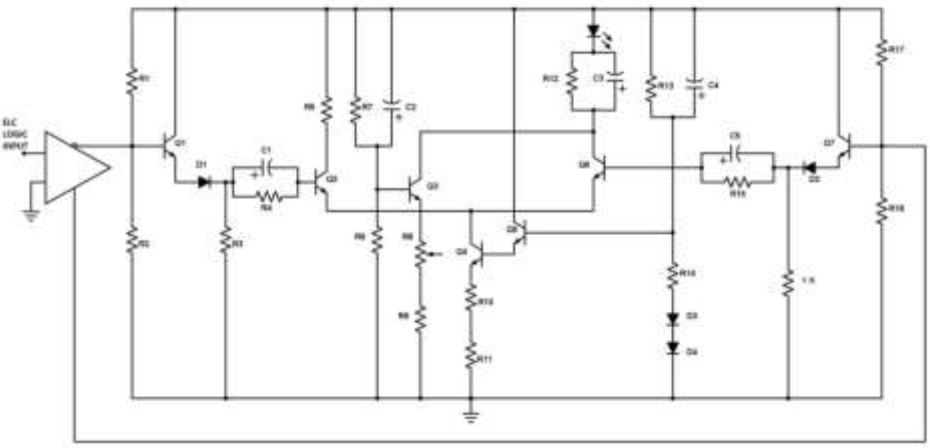


Figure 4. LED light source driving circuit

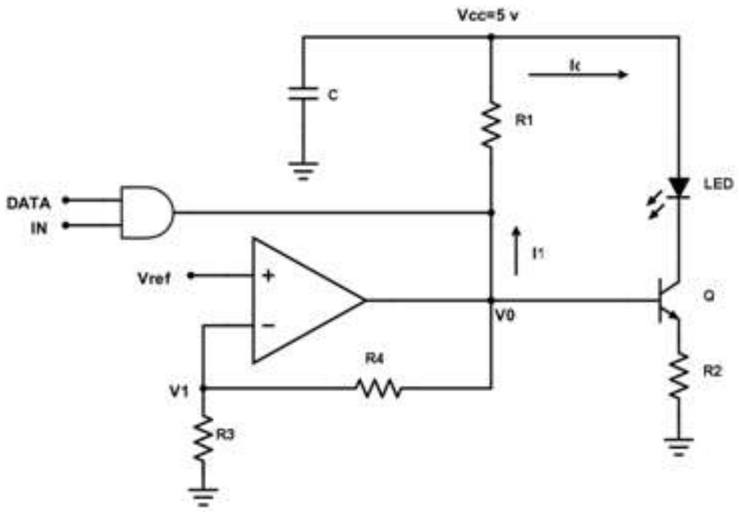


Figure 5. LED Transmitter

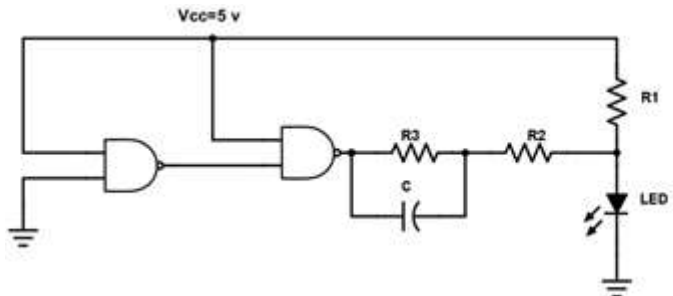


Figure 6.LED drive circuit

In the first stage:

Once the type of transmitter is selected, the program uses the following equations to compute the output risetime, bit rate and power:

$$risetime = TSP * ln\left|1 - \frac{I}{I_{th}}\right|$$

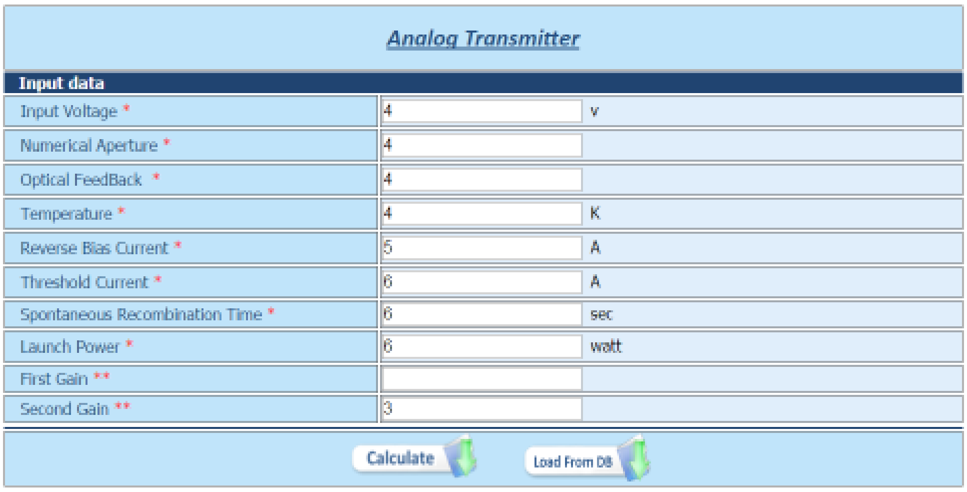
$$bitrate = \frac{0.5}{risetime}$$

$$power = V_T * ln\left|\frac{I}{I_o} + 1\right| * I$$

$$Launch\ Power = NA^2 * Power$$

Where, TSP : is the spontaneous recombination time
I : is the forward current
I_{th} : is the threshold current
V_T : is the thermal voltage (V_t= K.T/Q)
K: is Boltzmann constant
T: temperature in K^O
Q: electronic charge
I_o : is the reverse bias current
NA : Numerical Aperture

Figure 7 shows the input form of analog transmitter while Figure 9 shows the input form of digital transmitter. The input form in both Figures gives a description for every input parameter as well as giving the unit of the parameter. The designer has two options for data entering. He could input the data manually or call it from the database. Once all failed are filled with information, the designer could execute the program. The output form of the analog transmitter design is shown in Figure 8 while Figure 10 shows the output form of digital transmitter design.



Analog Transmitter

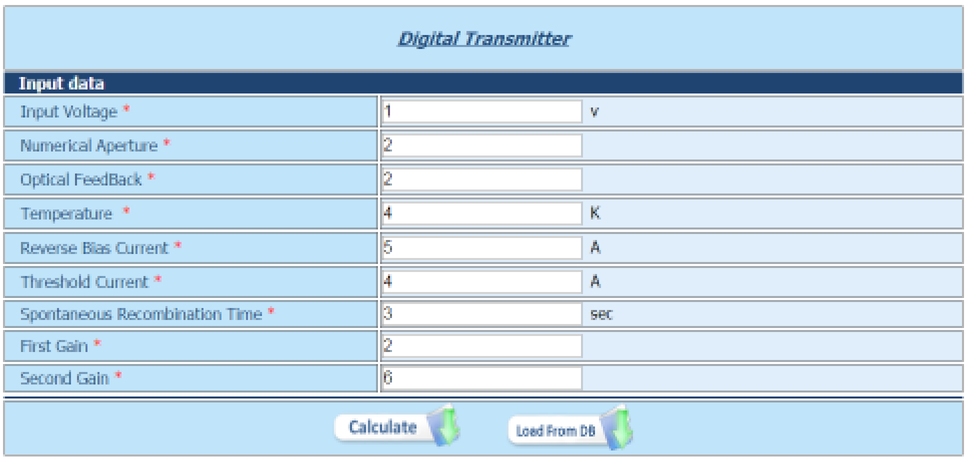
Input data		
Input Voltage *	4	v
Numerical Aperture *	4	
Optical FeedBack *	4	
Temperature *	4	K
Reverse Bias Current *	5	A
Threshold Current *	6	A
Spontaneous Recombination Time *	6	sec
Launch Power *	6	watt
First Gain **		
Second Gain **	3	

Calculate Load From DB

Figure 7. Analog Transmitter Input Form

Result		
Bitrate	-0.522069352846968	Mb/s
Risetime	-0.957727162633434	sec
First Gain	58288.9820875983	
Second Gain	3	
Output Power	1.64410702619543E-05	watt

Figure 8. Analog Transmitter Output Form



Digital Transmitter

Input data		
Input Voltage *	1	v
Numerical Aperture *	2	
Optical FeedBack *	2	
Temperature *	4	K
Reverse Bias Current *	5	A
Threshold Current *	4	A
Spontaneous Recombination Time *	3	sec
First Gain *	2	
Second Gain *	6	

Calculate Load From DB

Figure 9. Digital transmitter input form

Result		
Bitrate	-2.13811983387478	Mb/s
Risetime	-0.233850316562417	sec
First Gain	2	
Second Gain	6	
Output Power	0.00161431345168473	watt
Launch Power	0.00645725380673891	watt

Figure 10. Digital transmitter output form

In the second stage:
The LED driving circuit shown in Figure 4 is analyzed; the circuit is divided to three parts:

- Darlington Pair Source
- Q3 Current Source
- Light Source LED

The input form for every part of the circuit requests the designer to input values of some circuit components, and then the output voltage and current of every part are computed. Figure 11 through Figure 14 show the forms for all parts of the circuit, which include the required input data values and the result output.

Transmitter Driving Circuit Analysis (Darlington Pair)

Input data		
Vcc *	4	Volt
VD3 *	5	Volt
VD4 *	4	Volt
VBE(Q4) *	4	Volt
VBE(Q5) *	45	Volt
R10 *	5	K ohm
R11 *	5	K ohm
R13 *	6	K ohm
R14 *	6	K ohm

Calculate

Result		
I9	-0.416666666666667	mA
V1	6.5	Volt
I6	-4.25	mA
I7	-4.25	mA

The base current of Q4 transistor is very small , so , I6 = I7

Figure 11. Darlington Pair form

Equations used fordarlington pair source as follows:

$$I_9 = \frac{V_{cc} + V_{D3} + V_{D4}}{R_{13} + R_{14}}$$

$$V_1 = V_{cc} - I_9 R_{13}$$

$$I_7 = \frac{V_1 - V_{BE(Q5)} - V_{BE(Q4)}}{R_{10} + R_{11}}$$

Ignoring base current of Q_4,

$$I_6 = I_7 = \frac{V_1 - V_{BE(Q5)} - V_{BE(Q4)}}{R_{10} + R_{11}}$$

Figure 12. Q3 current Source form

Equations used forQ3 current source as follows:

$$I_9 = \frac{V_{cc} + V_{D3} + V_{D4}}{R_{13} + R_{14}}$$

Ignoring base current of Q_3,

$$I_2 = \frac{V_{cc}}{R_6 + R_7}$$

$$I_1 = I_2 = \frac{V_{cc}}{R_6 + R_7}$$

Then the voltage at the base of Q_3 is

$$V_2 = V_{cc} - I_1 R_7$$

It is possible then to calculate the current I_3 passing through the emitter of Q_3,

$$I_3 = \frac{V_2 - V_{BE(Q3)}}{R_8 + R_9}$$

The current L_4 passing through the collector of Q_3 approximately equals to I_3,

$$I_4 = I_3 = \frac{V_{cc} - \frac{V_{cc}}{R_6+R_7} R_7 - V_{BE(Q3)}}{R_8 + R_9}$$

Figure 13. Light Source LED (ON State) form

Equations used forlight source LED (ONState) as follows:

If a high logic at the input of the line receiver is received, the line receiver is negatively coupled to Q_1 to switch it OFF. At the same time the high logic is fed through to Q_7 which will be turned ON. Q_7 will then drive Q_6 to ON state brining down the common emitter junction voltage causing Q_2 to be completely switched OFF. The current I_6 will be completely drawn through the only path of Q_6. Therefore,

$$I_8 = I_6 = \frac{V_{cc} - \frac{V_{cc} - V_{D3} - V_{D4}}{R_{13}+R_{14}} R_{13} - V_{BE(Q5)} - V_{BE(Q4)}}{R_{10} + R_{11}}$$

$$I_4 = \frac{V_{cc} - \frac{V_{cc}}{R_6+R_7} R_7 - V_{BE(Q3)}}{R_8 + R_9}$$

$$I_5 = I_4 + I_8$$

Therefore,

$$I_{LED(ON)} = \frac{V_{cc} - \frac{V_{cc}}{R_6+R_7} R_7 - V_{BE(Q3)}}{R_8 + R_9} + \frac{V_{cc} - \frac{V_{cc} - V_{D3} - V_{D4}}{R_{13}+R_{14}} R_{13} - V_{BE(Q5)} - V_{BE(Q4)}}{R_{10} + R_{11}}$$

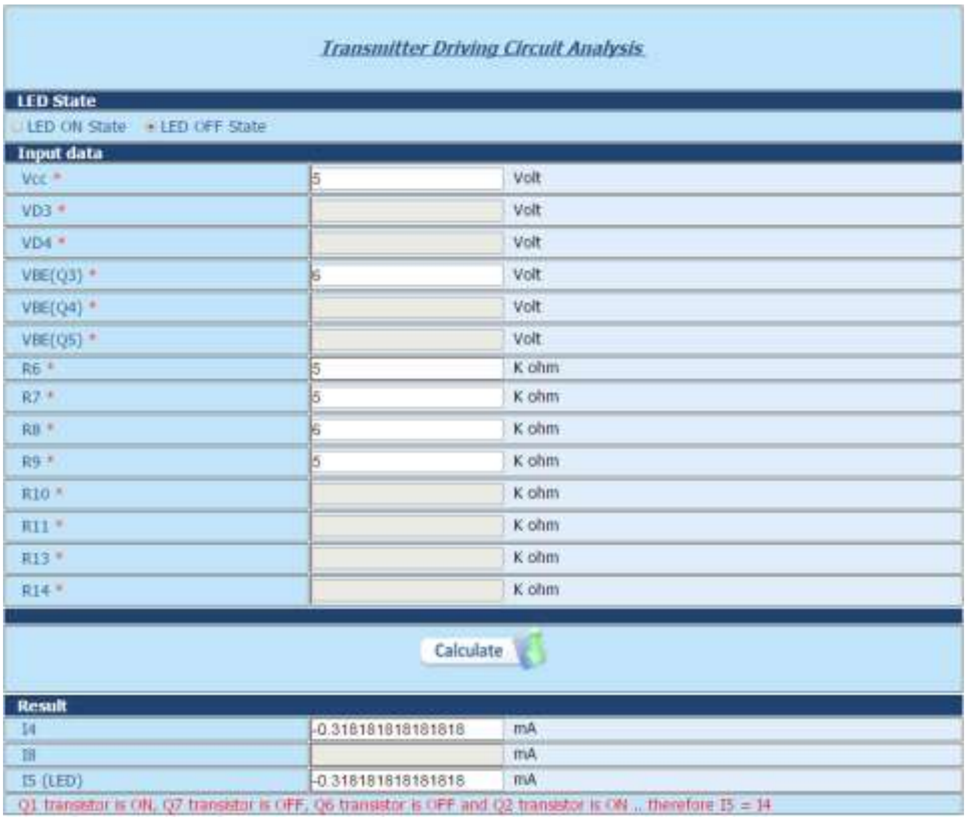


Figure 14. Light Source LED (Off State) form

Equations used forlight source LED (Off State) as follows:

On the other state, receiving zero logic at the input will drive the circuit in the opposite manner, that is, Q_1 is turned ON driving Q_2 also ON, Q_7 will be OFF and as a result Q_6 will be turned OFF. The current I_6 drawn by the Darlington pair source will be routed through Q_2. Therefore, the only current passing through the LED is the current of Q_3, namely I_4. Then,

$$I_5 = I_4$$

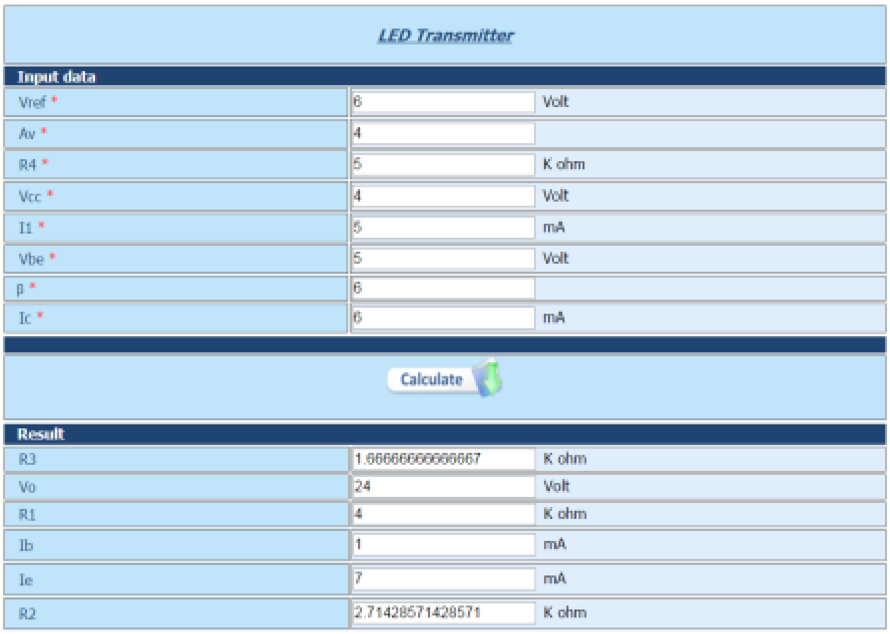
Because $I_8 = 0$, then

$$I_{LED(OFF)} = \frac{V_{cc} - \frac{V_{cc}}{R_6+R_7} R_7 - V_{BE(Q3)}}{R_8 + R_9}$$

The current passing through the LED alternates between two values, either the summation of I_4 and I_6, or I_4 alone depends upon the input state.After making these calculations, the program asks the user if the output result of the design meets the required specification, if yes, the user is able then to save the design to a file otherwise the program refreshes all input parameters allowing the user to reenter a new values.

In the third stage:

The LED transmitter circuit is shown in Figure 5, the output form including the required input values are shown in Figure 15. LED driver circuit is shown in Figure 6, the output form including the required input values are shown in Figure 16.



LED Transmitter		
Input data		
Vref *	6	Volt
Av *	4	
R4 *	5	K ohm
Vcc *	4	Volt
I1 *	5	mA
Vbe *	5	Volt
β *	6	
Ic *	6	mA
Calculate		
Result		
R3	1.66666666666667	K ohm
Vo	24	Volt
R1	4	K ohm
Ib	1	mA
Ie	7	mA
R2	2.71428571428571	K ohm

Figure 15. LED transmitter form

Equations used in this LED transmitter as follows:

$$R_3 = \frac{R_4}{A_V - 1}$$

$$V_0 = V_{REF} * A_V$$

$$R_1 = \frac{V_0 - V_{cc}}{I_1}$$

$$I_B = \frac{I_c}{\beta}$$

$$I_E = I_B + I_c$$

$$R_2 = \frac{V_0 - V_{BE}}{I_E}$$

LED Driver		
Input data		
Vcc *	5	Volt
V1 *	4	Volt
R1 *	4	K ohm
R2 *	3	K ohm
I3 *	3	mA
R3 *	3	K ohm
Calculate		
Result		
I1	0.25	mA
I2	2.75	mA
V2	12.25	Volt
V3	20.5	Volt

Figure 16. LED driver form

Equations used in this LED driver as follows:

$$I_1 = \frac{V_{cc} - V_1}{R_1}$$
$$I_2 = I_3 + I_1$$
$$I_B = \frac{I_c}{\beta}$$
$$V_2 = V_1 * R_2 * I_2$$
$$V_3 = V_2 * R_3 * I_2$$

IV. Fiber Optic Cables

The fiber optic is the medium, which guides the light from the transmitter to the receiver. The fiber cable is composed of single or multiple waveguides sheathed in a protective jacketing material; this jacketing is also multilayer. However, the waveguide is responsible for the optical transmission characteristics of the cable. Jacketing material and a protective coating shield the waveguides from environmental effects and add mechanical strength.

Fibers allow relatively loss-free data transfer over distances that may eventually range from a few meters to hundreds or thousands ofkilometers. So, fiber opticsare being extensively used in applications like local area networks where a large volume of data is required to be transmitted over a number of terminals located in a geographically small area. Such network will be free from external interference and will offer higher data rates. They will work reliably even in a hostile environment which may be due to electromagnetic interference (EMI), electrostatic discharges, corrosive atmosphere, etc. An additional advantage will be the absence of an unauthorized tapping of data from lines.

Most fiber opticsare made of glass. Glass offers the lowest achievable loss and dispersion, whereas waveguide made of plastic are characterized by loss and dispersion that are frequently higher by one or more orders of magnitude [5].

4.1Types of Fiber optic cable

Fiber optic cable can be classified based on propagation mode as single mode and multimode [6], [7] (Figure 17). These provide a different performance regarding both the attenuation and dispersion time.

In Single mode Fiber (sometimes called monomode) light can going in straight line only, because it is very small core diameter. Single mode is higher bandwidth, lower fiber attenuation and used for long transmission.

In multimode fiber the light take any number of paths. The difference in the core diameter is the major difference between multimode and single mode. Multimode fibers usually have a wider core that makes it easier to couple to the source or detector. The multimode fiber optic can classified based on refractive index into two types: step index and graded index multimode

Step index multimode specifications:

- The density of core remains constant from the center to edges until it reaches the interface of the core and the cladding.
- Beams in the middle travel in straight the core and reach the destination without reflecting or refraction.
- Other beans strike the interface of the core and cladding at different angles causing the beams to reach the destination at different times.
- Mostly used for imaging and illumination

Graded index multimode specifications:

- It is fiber with varying density (highest at center of the core and decrease gradually to its lowest at the edge).
- This difference causes the beams to reach the destination at regular intervals.
- Can be used over distance of up to about 1000 meters.
- Used for data communication and networks carrying signals for typically no more than a couple of kilometers.

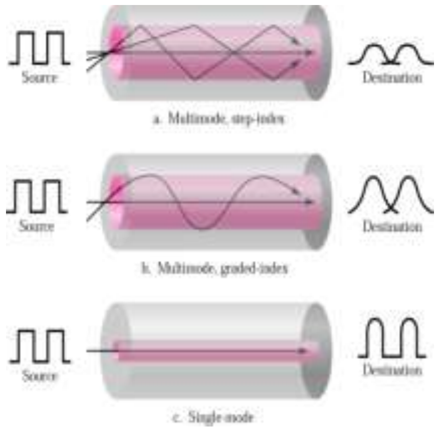


Figure 17. Single mode and Multimode

4.2Fiber Optic Transmission Characteristics

Attenuation and dispersion are the difficulties facing fiber optic (Figure 18); the attenuation effect reduces the signal power and it is caused by absorption losses, scattering losses and losses due to mechanical handling. Dispersion is the spreading of the signal over time. Dispersion mechanisms: Modal (or intermodal) dispersion, Chromatic dispersion (CD) and Polarization mode dispersion (PMD) [8].

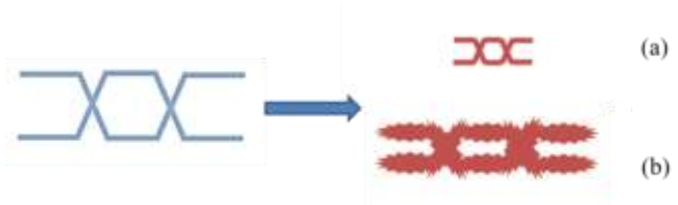


Figure 18. (a) Attenuation , (b) Dispersion

4.2.1 Attenuation

The attenuation or transmission loss determines the maximum distance prior to signal restoration, optical fiber communications became especially attractive when the transmission losses of fibers were reduced below those of the competing metallic conductors (less than 5 dB/km).

In optical fiber communications the attenuation is usually expressed in decibels per unit length as following:

$$\alpha_{dB} L = 10 log_{10} \frac{P_i}{P_o}$$

Where;

α : attenuation (dB).
P_i : input power.
P_o : output power.
L : length (km).

The basic attenuation mechanisms in a fiber are absorption, scattering, and radiation losses of the optical energy.

Absorption Losses

Absorption is defined as the portion of attenuation resulting from light is absorbed due to chemical properties of the fiber so that less energy is emitted. Attenuation by absorption is caused by:

- Atomic defects in the glass.
- Impurity atoms in the glass composition (Extrinsic absorption).
- The basic constituent atoms of the fiber material.

Scattering Losses

Light is re-directed by the molecular properties of the fiber resulting in leakage into the cladding, jacket, or lost at junctions. Scattering losses are caused by:

- Microscopic variations in the material density.
- Compositional fluctuations
- Structural inhomogeneities or defects occurring during the fiber manufacturing.

Losses due to Mechanical Handling
Radiative Losses (Microbending Losses):this type of losses occurs whenever an optical fiber undergoes a bend of finite radius of curvature. The two types of bends are:

- Bends having radii that are large compared to the fiber diameter such as when the fiber cable turns a comer.
- Random microscopic bends of the fiber axis that can arise when the fibers are incorporated into cables [3].

Joint Losses:there are inherent connection problems when jointing fibers with, for instance:

- Different core and/or cladding diameters;
- Different numerical aperture and/or relative index differences;
- Different refractive index profiles;
- Fiber faults

The best results are therefore achieved with compatible (same) fibers, which are manufactured to the lowest tolerance. In this case there is still some jointing problem such as the mechanical alignment between the two fibers being jointed, the fiber end face quality, and the cleanliness of the fiber end-faces. Figure 19 illustrates examples of possible misalignment between coupled compatible optical fiber.

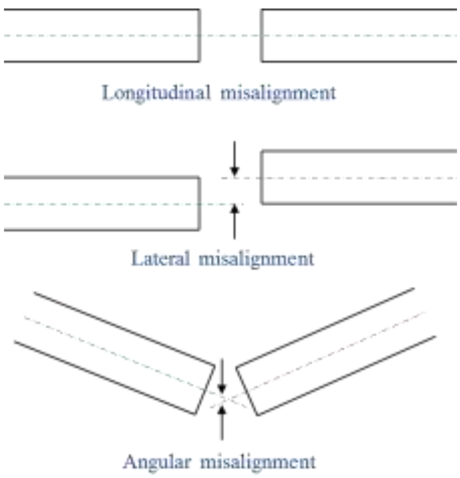


Fig 2.23. The three possible misalignments which may occur when jointing compatible optical fibers

As shown in Figure 19, the misalignment may occur in three dimensions, the separation between the fibers (longitudinal misalignment), the offset perpendicular to the fiber core axes (lateral/radial/axial misalignment) and the angle between the core axes (angular misalignment).

4.2.2 Dispersion

Dispersion in fiber is one of the most important fiber characteristics because, it directly affects the bandwidth of the fiber and hence the speed at which data can be sent over the fiber [3]. The basic dispersion mechanisms in a fiber are: Modal (or intermodal) dispersion, Chromatic dispersion (CD) and Polarization mode dispersion (PMD).

- Modal dispersion: Spreading of the signal over time resulting from the different propagation modes in the fiber.
- Chromatic dispersion: Spreading of the signal over time resulting from the different speeds of light rays.
- Polarization mode dispersion: Orthogonal light waves travel at different speeds in the fiber

4.3Fiber Optic Links Design

A general flowchart for fiber optic cables design is shown in Figure 20. The user is requested to enter the cable specification and then to select either multimode or monomode cable, the input parameters are described in the input form which is shown in Figure 21.

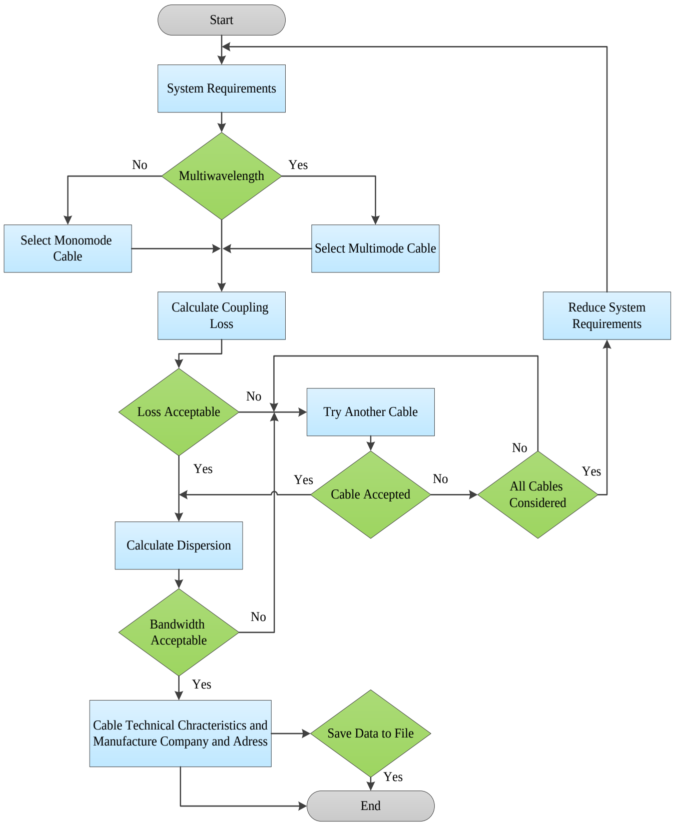


Figure 20. Fiber Optic Cables Design Flowchart

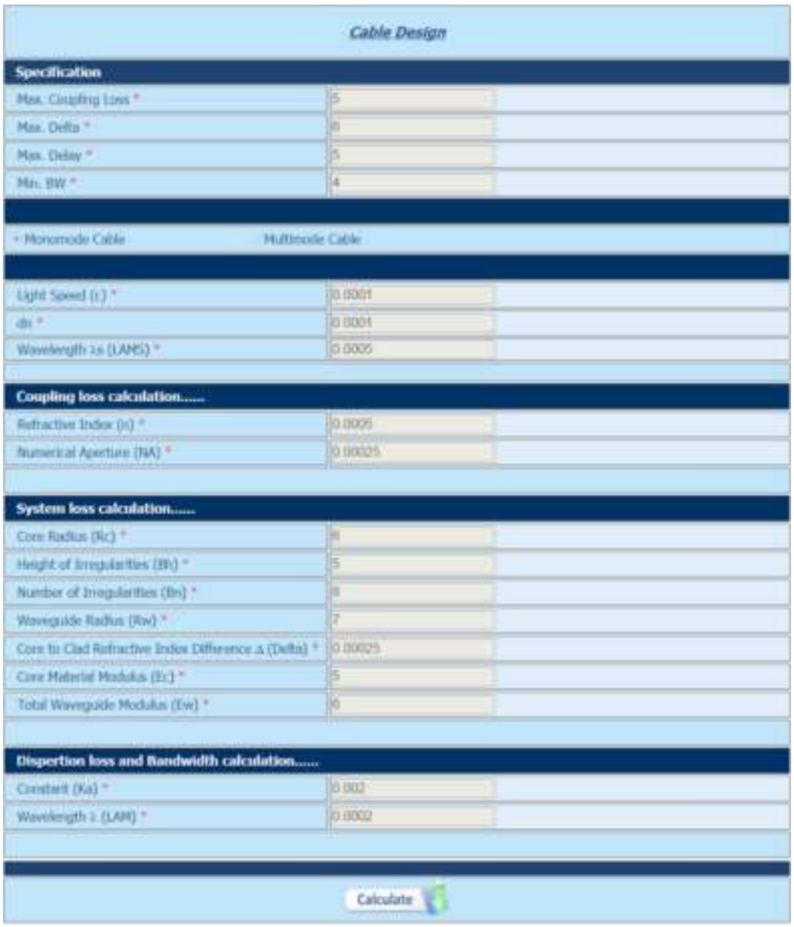


Figure 21. Cable Design Input form

Once the input data is entered, the program will compute the coupling loss, system loss, delay, and bandwidth as shown in Figure 22. If the calculated coupling loss, system loss, delay are less than the maximum accepted values and the bandwidth is greater than the minimum accepted value specified by the user, the program will accepts the design and allows the user to save his design in a file containing all inputs and output data of cable design. If one of design parameters does not meet the specification the program shows a massage telling the user to change the input data (choose another cable) or reduce the design specification.

Result (Monomode Cable)		
Coupling Loss	-75.0493288534768	
System Loss	96537794222.0259	
Delay	6.26996810199223E-11	
Bandwidth	79745222282890	

Figure 22. Cable Design Output form

Equations used in cable design as follows:

$$CouplinLoss = 10\log\left(\frac{n+1}{2} * na^2\right)$$

$$SysLoss = 0.9\,\frac{r_c^4 B_h^2 B_n}{\Delta^2 r_w^6} * \left(\frac{E_c}{E_w}\right)^{\frac{3}{2}}$$

$$Delay = \frac{1}{c} * \sqrt{\left(\frac{n * delta * k_a}{2}\right)^2 + (lam * lams * \; d_n)^2}$$

$$BW = \frac{1}{c * \sqrt{\left(\frac{n*delta\,*k_a}{2}\right)^2 + (lam * lams * \; d_n)^2}}$$

V. Optical Receiver

The receiver converts the optical signal back to it original form. As shown in Figure 2receiver consists of fiber to light interface, light detector, amplifier, shaper and decoder.Light detector is sensitive device used to detect the light pulses and converts back the light pulses into an electrical signal. The electrical pulses are amplified and reshaped back into digital form.

The light detector, usually a semiconductor photodiode; must convert the normally weak optical signal into a corresponding weak electrical signal. Subsequent stages in the receiver provide amplification and single processing. The output of the receiver is an electrical signal that meets user-defined specifications concerning signal power, impedance level, bandwidth, and other parameters [9].

In order to achieve this objective the optical receiver should possess the following characteristics:

- High sensitivity and must be suitably matched to the wavelength of the optical source.
- Wide bandwidth (i.e. high speed response)
- Small additional noise.
- No change of characteristics with external conditions.
- Reasonable source voltage requirements.

Two types of semiconductor devices largely satisfy the above mentioned conditions, namely, the PIN photodiode and the Avalanche photodiode (APD).

A positive-intrinsic-negative (p-i-n) photodiode consists of *p* and *n* regions separated by a very lightly *n* doped intrinsic region. Silicon p-i-n photodiodes are used at 0.8 nm wavelength and InGaAs p-i-n photodiodes at 1.3 and1.55 nm wavelengths. In normal operation, the p-i-n photodiode is under high reverse bias voltage. So the intrinsic region of the diode is fully depleted of the carriers. When an incident photon has energy greater than or equal to the band gap energy of the photodiode material, the electron-hole pair is created due to the absorption of photon. Such photons generate carriers in the depleted intrinsic region, where most of the incident light photons absorbed are separated by the high electric field present in the depletion region and are collected across the reverse biased junction. This produces a photocurrent flow in the external circuit to get high quantum efficiency and hence the maximum sensitivity and the thickness of the depletion layer should be increased so that the absorption of photons will be maximum. InGaAs p-i-n photodiodes have high quantum efficiency and high responsivity in the 1.33 and 1.55nm wavelengths.

Avalanche photodiode (APD) consists of four regions *p+ - i– p-n+* to develop very high electric field in the intrinsic region and to impart more energy to photoelectrons to generate new electron-hole pairs by impact ionization leading to avalanche breakdown in the reverse biased diode. The APDs have therefore, high sensitivity and high responsivity over p-i-n diodes due to the avalanche multiplication. APDs are made from silicon or germanium having operating wavelength of 0.8 nm and InGaAs with operating wavelength of 1.55 nm [9].Fig. 8 shows various types of detectors and their spectral responses.

5.1PIN and APD Performance Comparison

Most optical detectors suffer from two major difficulties: the slow-tail frequency response of non-avalanching (PIN) devices and the temperature dependence of the avalanche process of avalanching (APD) devices. The speed of optical detectors is largely a function of the detector capacitance, which is composed of the device and package contributions. The device capacitance depends upon the width of the depletion layer and is therefore a function of the impurity concentration and the applied voltage. Since a large operating voltage effects a wide depletion layer and hence a smaller capacitance compared to an otherwise identical device operated at low voltage, APDs usually have a higher frequency response than PINs.

The avalanche voltage is a sensitive function to temperature, so that avalanche photo detectors require the addition of temperature-compensating circuitry [3]. The responsivity of an APD at unity gam has the same dependence as a PIN photo detector biased at a low voltage. At higher reverse biases, multiplication occurs and the photocurrent multiplication (gain) increases. The responsivity of an APD is then responsivity of a PIN photodetector multiplied by the gain, M [3].

5.2Optical Receiver Design

A receiver for optical communication signals mainly consists of a photodiode, a preamplifier and an equalizer. The minimum acceptable optical signal power at the receiver depends upon the photodiode gain and the noise introduced by the photodiode and the preamplifier. Thus the design of an optimum receiver calls for optimum photodiode gain and an optimum preamplifier. V.K Jain, P.Kumar, and S.N.Gupta have reported design of an optimum optical receiver published in Journal of Optical Communications in 1985. The design shows that for an optimum receiver there exists a particular bias current at which the optical power required is minimum. However, this optimum bias current is not critical. Also optical power required will be minimum for APD/PIN diode having the minimum junction capacitance and will vary inversely with quantum efficiency and directly with the junction capacitance. Figure 23 illustrates the general design flowchart of optimum optical receiver.

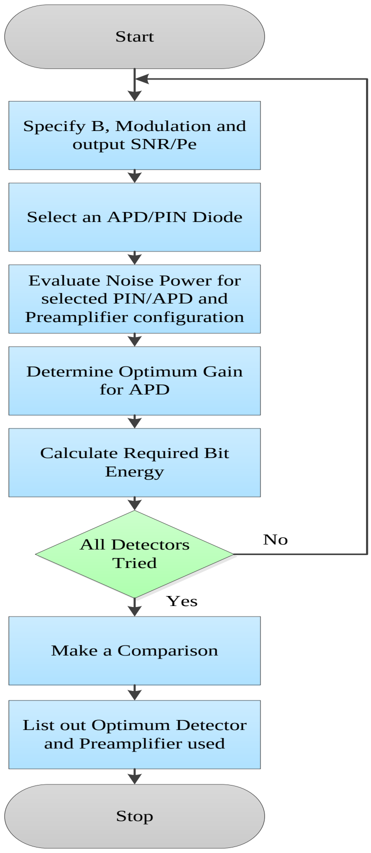
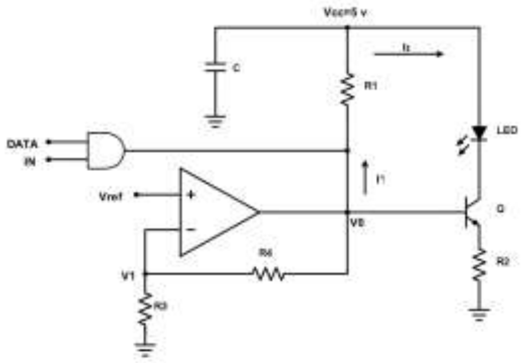
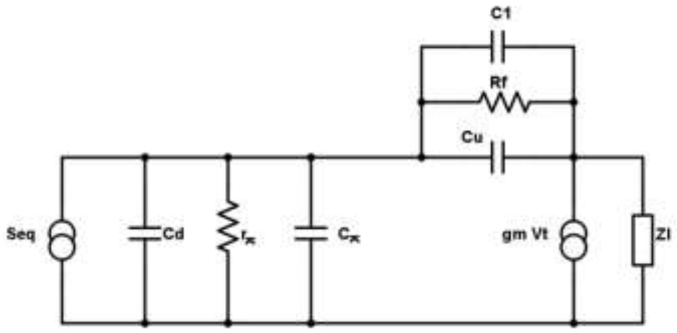


Figure 23. Flowchart of optimum optical receiver

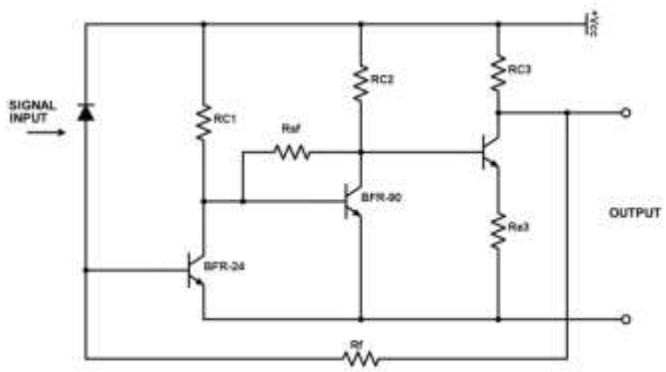
The transimpedance preamplifier and its noise model are shown in Figures 24 and Figures 25 respectively, and the Optimum receiver configuration is shown in Figure 26.



Figures 24. Transimpedance preamplifier



Figures 25. Transimpedance preamplifier noise model

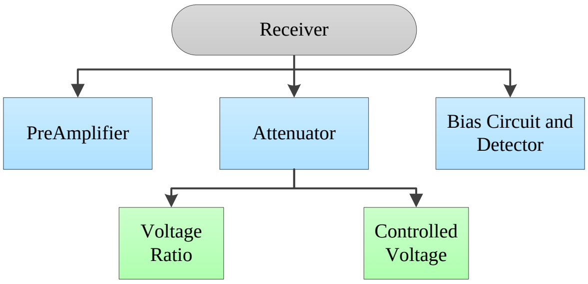


Figures 26. Optimum receiver configuration

Where;

Ri, Ci : are the input resistance and capacitance of the amplifier
A : is the closed loop mid-frequency voltage gain
Cd : is the junction capacitance of the photodiode
Rf, Cf : are the feedback resistance and capacitance, respectively
$r\pi$, $C\pi$: are the transistor base-to-emitter resistance and capacitance, Respectively.
Cb : is the bias current I_b dependent capacitance
Cu : is the transistor base-to-collector capacitance
g_m : is the transconductance of transistors
I_d : is the diode current

The exact design of an optimum optical receiver is used here where, all approximations in the circuits analysis and in the equations derivation have been replaced with exact solutions. This because, the design is implemented in a computer program at which the exact design can be easily achieved. The program is linked with a database, which allows the designer to call any stored data for any part of the optical receiver. The designer is also offered to enter his own input data if needed. The output result of the design gives almost all required details and allows the designer to save the results to file and then print it out if required. The general flowchart of the optimum optical receiver program is shown in Figure 27.



Figures 27. The general flowchart of the optimum optical receiver program

Fiber optics receiver consists of three parts, they are:
- Preamplifier
- Bias circuit and detector
- Attenuator

The receiver design program allows the designer to design any part of those mentioned above. This of-course gives the designer more flexibility to vary the receiver components according to the specification and the cost.

5.2.1 Preamplifier

The preamplifier input form is shown in Figure 28:

Receiver PreAmplifier		
APD Or PIN Specefications		
Bandwidth (BW) *	6	Hz
Wavelength (λ) *	3	
Temperature (T) *	2	K
Junction Capacitance (Cd) *	2	F
Transistor used in the Amplifer		
Current Gain (β) *	4	
Bias Resistance (R_π) *	6	Ohm
Bias Capacitance (C_π) *	3	F
Bias Current Ib Dependent Capacitance (Cb) *	4	F
Transistor Base to Collector Capacitance (Cu) *	8	F

Figures 28. Receiver Preamplifier Input form

The input form describes the required input parameters; Figure24 and Figure25respectively show the circuit layout of the preamplifier. The designer can enter the data manually or call it from database. The output is shown in Figure 29:

PreAmplifier Specefications		
Bias DC Current (I_b)	24403.9824246869	µA
Loop Feedback Resistance (R_{sf})	3.31572798064821E-06	K Ohm
Overall Feedback (R_f)	4.47676466746879E-09	K Ohm
Initial Amplifier Gain (A)	0.00221048532043214	
Exact Amplifier Gain	-5.19305883978502E-12	

Fig. 29: Receiver Preamplifier Output form

Equations used in this preamplifier as follows:

The bias DC current I_b follows:

$$I_b = \frac{2\pi * \mathrm{BW} * V_T * C_A}{\sqrt{3\beta + 4(\pi * \mathrm{BW} * V_T * C_b)^2}}$$

Where,

$$C_A = C_d + C_u + C_f + C_\pi$$
$$V_T = KT/q$$

K : is the Boltzmann constant
q : is the electronic charge

Then the program varies the bias DC current I_b a step of lE-7 until it reaches to a value at which the required input power and the junction capacitance have the minimum values, At this value of the bias current. The Loop Feedback Res. follows:

$$R_{sf} = \frac{1}{2\pi * \mathrm{BW} * \left(C_u + C_f\right)}$$

The Overall Feedback follows:

$$R_f = \frac{-g_m * R_{sf} * R_c3}{2\pi * \mathrm{BW} * \mathrm{C} * R_e3}$$
$$C = C_A + C_b * I_b$$

The initial amplifier gain:

$$A = 2\pi * C * R_f * BW$$

The exact gain can be driven from circuit shown in Figure 26 as follows:

$$X_1 = (\beta + 1) * R_e3$$
$$X_2 = \beta * R_c3$$
$$R_{I3} = R_\pi + \frac{X_1 * X_2}{X_1 + X_2}$$
$$X_1 = \frac{R_{sf} * R_c3}{R_{sf} + R_c3}$$
$$RM = \frac{\beta * X_1 * R_{I3} * R_{sf}}{(X_1 + R_{I3}) * \left(R_{sf} + R_\pi\right)}$$
$$BE = \frac{-1}{R_{sf}}$$
$$DE = 1 + BE * RM$$
$$RMF = \frac{RM}{DE}$$
$$AVF = \frac{-RMF}{R_c3}$$
$$D_2 = \frac{1}{1 - AVF}$$
$$X_1 = \beta * R_c3$$
$$X_2 = \beta * R_{sf} * D_2$$
$$X_1 = \frac{X_1 * X_2}{X_1 + X_2}$$
$$X_2 = \beta * R_I3$$
$$R_{12} = \frac{X_1 * X_2}{X_1 + X_2}$$
$$A_1 = \frac{\beta * \frac{R_c3 * R_{I2}}{R_c3 + R_{I2}}}{R_\pi}$$

$$A_3 = \frac{\beta * R_c 3}{(\beta + 1) R_e 3}$$

$$ExactGain = A_1 * AVF * A_3$$

$$BE = \frac{-1}{R_f}$$

$$DE = 1 + BE * ExactGain$$

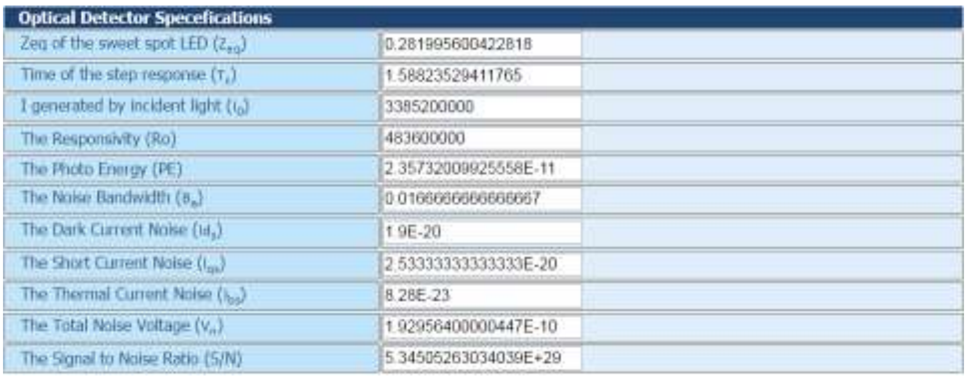
$$ExactGain = \frac{ExactGain}{DE}$$

5.2.2 Bias Circuit and Detector

The input parameters are described in the input form and the designer can enter the data manually or call it from database, which is shown in Figure 30. The output is shown in Figure 31.

Receiver Optical Detector		
APD Or PIN Specefications		
Junction Cpacitance (c_d) *	1	F
Dynamic Resistance (R_d) *	2	Ohm
Operating Frequency (F) *	3	Hz
Source Parameters		
Source Impedance (R_s) *	4	Ohm
Load Impedance (R_L) *	5	Ohm
Current Gain (β) *	6	
Photodiode and Bais Circuit		
Incident Power (P) *	7	watt
Efficiency (G) *	6	
Noise Factor (F_a) *	6	
Temperature (T) *	45	K
Equivalent Resistance, Capacitance and Noise Current		
Dark Current Noise (I_d) *	3	A
Short Noise Current (I_{0e}) *	4	A
Total Capacitance (C_t) *	5	F
Equivalent Resistance (R) *	3	Ohm
Calculate	Load From DB	

Figures 30. Receiver Optical Detector Input form



Optical Detector Specefications	
Zeq of the sweet spot LED (Z_{eq})	0.281995600422818
Time of the step response (τ_r)	1.58823529411765
I generated by incident light (i_0)	3385200000
The Responsivity (Ro)	483600000
The Photo Energy (PE)	2.35732009925558E-11
The Noise Bandwidth (B_e)	0.0166666666666667
The Dark Current Noise (id_s)	1.9E-20
The Short Current Noise (i_{qs})	2.53333333333333E-20
The Thermal Current Noise (i_{bs})	8.28E-23
The Total Noise Voltage (V_n)	1.92956400000447E-10
The Signal to Noise Ratio (S/N)	5.34505263034039E+29

Figures 31. Receiver Optical Detector Output

Equations used for optical detector as follows:
Zeq of the sweet spot LED:

$$Z_{eq} = \sqrt{\frac{\frac{R_d}{w} c_d}{{R_d}^2 + \left(\frac{1}{w} c_d\right)^2} + \frac{\frac{{R_d}^2}{w} c_d}{{R_d}^2 + \left(\frac{1}{w} c_d\right)^2}}$$

Where, w = 2πF

Time of Step Response:

$$T_c = \frac{R_s + R_L}{\frac{R_s}{\beta} + R_L}$$

I generated by incident light:

$$I_0 = P * G * 0.806 * \lambda$$

The Responsivity:

$$R_0 = 0.806 * \lambda * G$$

The Photo Energy:

$$PE = \frac{e}{0.806} * \lambda$$

Where, e = electron charge

The Noise Bandwidth:

$$B_a = \frac{1}{4 * C_t * R}$$

The Dark Current Noise:

$$Id_s = 2 * I_d * e * B_a$$

The Short Current Noise:

$$I_{qs} = 2 * I_{0e} * e * B_a$$

The Thermal Current Noise:

$$I_{bs} = \frac{4 * K * T * B_a * F_a}{R}$$

The Total Noise Voltage:

$$V_n = 2 * e * I_0 * B_a * R^2 + \frac{4 * K * T * B_a * F_a * R^2}{R_L}$$

The Signal to Noise Ratio:

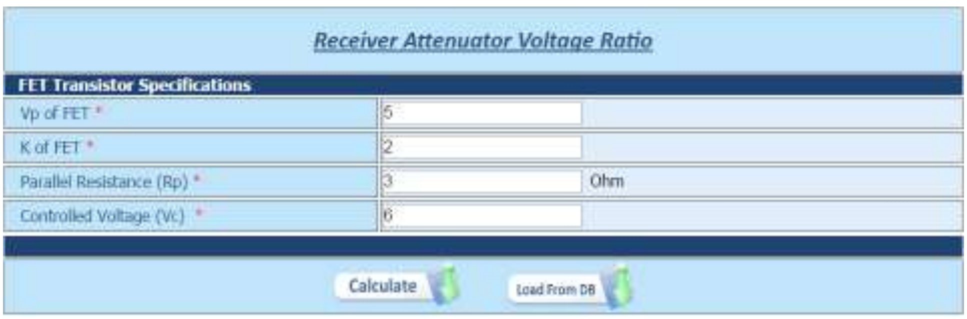
$$S/N = \frac{{I_0}^2}{2 * I_0 * e * B_a * 16 * K * T * B_a * C_t * F_a}$$

5.2.3 Attenuator

The attenuator program presents two options to the designer, they are:

- Design for voltage ratio V_o/V_{in} in in controlled voltage V_c is known.
- Design for controlled voltage V_c if voltage ratio V_o/V_{in} is known.

Figure 32 and Figure 33 show the attenuator input forms for both options respectively.



Figures 32. Receiver Attenuator input form (design for voltage ratio).

Figures 33. Receiver Attenuator input form (design for controlled voltage).

The output forms for both cases are shown in Figure 34 and Figure 35respectively.

Figures 34. Receiver Attenuator Output form (design for voltage ratio).

Figures 35. Receiver Attenuator input form (design for controlled voltage).

Equations used in attenuator as follows:
Controlled Voltage,

$$V_c = \frac{1}{K * \left(\frac{V_r}{R_p} - R_p\right)} + V_p$$

Voltage Ratio,

$$V_r = \frac{R_p}{R_p + R_f}$$

Where,

$$R_f = \frac{1}{K\left(V_c - V_p\right)}$$

VI. Conclusion

Advantages of fiber optic communication have been discussed. Thethe different parts of the optical communication system have been discussed, starting at the optical source and ending at the optical detector. Powerful software has been developed, in order to deal with each individual part of fiber optic communication system.

References

[1] Andrew S. Tanenbaum, "Computer Networks", 4th Edition, Prentice Hall PTR.
[2] F. C. Allard, "Fiber optics handbook: for engineers and scientists", McGraw-Hill.
[3] J. Senior, "Optical fiber communications: principles and practice", 3rd Edition, Prentice Hall PTR.
[4] O. Strobel and J. Lubkoll, "Fiber-Optic Communication-An Overview", 20th Int. Crimean Conference Microwave & Telecommunication Technology, 2010.
[5] "Fundamentals of Fiber Cable Management", ADC Telecommunications, Inc.
[6] P. Sharma, R. Arora, S. Pardeshi and M. Singh, "Fibre Optic Communications: An Overview", International Journal of Emerging Technology and Advanced Engineering, vol. 3, issue 5, pp. 474-479, 2013.
[7] M. Arumugam, "Optical Fibre Communication – An Overview", Pramana journal of physics, vol. 57, pp. 849–869, 2001.
[8] V. Alwayn, "Optical Network Design and Implementation", Cisco Press. Part of the Networking Technology series, 2004.
[9] M. Nick, "Fiber Optic Telecommunication", Springfield Technical Community College Springfield, Massachusetts, University of Connecticut, 2000.