Study of optical fiber parameters under non-linear condition

By

Dipankar Singh(17/ECE/91)
Debjit Biswas(17ECE/92)
Biswajit Khan(17/ECE/94)
Avinandan Mondal(17/ECE/96)
Amit Mondal(17/ECE/107)

A Project thesis Submitted to Haldia Institute of Technology

In Partial Fulfilment of the Requirements for Degree of

B. Tech in Electronics & Communication Engineering,

Maulana Abul Kalam Azad University of Technology,

Formerly known as West Bengal University of Technology

UNDER THE SUPERVISION OF

Mr. Tilak Mukherjee
Asst. Prof. Dept of ECE,HIT

DEPARTMENT OF ELECTRONICS
&
COMMUNICATION ENGINEERING
HALDIA INSTITUTE OF TECHNOLOGY
2021

HALDIA INSTITUTE OF TECHNOLOGY

(An Institution of ICARE)

(Approved by AICTE, New Delhi)

(Affiliated to Maulana Abul Kalam Azad University of technology, West Bengal)

(Formerly known as West Bengal University of Technology-WBUT)

P.O- HIT, Haldia,Dist.- Purba Medinipur,West Bengal, Pin-721657, West , INDIA

CERTIFICATE

This is to certify that the thesis entitled **"Study of optical fibre Parameters under non linear condition"** submitted by (Dipankar Singh,Debjit Biswas,Biswajit Khan,Avinandan Mondal,Amit Mondal) are absolutely based upon their work under the supervision of Mr. Tilak Mukherjee, Asst. Prof. Dept of ECE,HIT and that neither this thesis nor any part of it has been submitted for any degree/diploma or any other academic award anywhere before.

----------------------------------	--------------------------------
(Prof.(Dr.) Chanchal Kr. De)	Mr.Tilak Mukherjee
HOD of Electronics & Communication Engineering,	Asst. Prof. Dept. Of ECE,HIT
Haldia Institute of Technology	Haldia Institute of Technology

ACKNOWLEDGEMENT

We are grateful to Almighty God for giving me the strength, knowledge and understanding to complete this project. His love has been more than sufficient to keep and sustain me. Our profound gratitude goes to our wonderful Project Coordinator Prof. Tilak Mukherjee for his invaluable support, patience, time and guidance in seeing us to the completion of this project work. Also my gratitude goes to our head of the department Prof. Dr. Chanchal Kumar De who patiently saw us to the completion of this research work.

We also extend gratitude and appreciation to our lecturers in Electronics and Communication Engineering department who have taught us at one point or the other. May God continue to bless, protect and guide you all

we also wish to acknowledge the great support of our parents, siblings who have been a source of inspiration towards my academic pursuit. God bless you all.

ABSTRACT

The intended application of our study of optical fiber parameters under non linear condition. In this report we discuss about the Optical Fiber and its advantages, Theory and principles of the fiber optics, Fiber geometry, Types of optical fiber, Different parameters and characteristics of fiber are also explained. Fiber has linear and non-linear characteristics. Linear characteristics are wavelength window, bandwidth, attenuation and dispersion. Non-linear characteristics depend on the fiber manufacturing, geometry etc.Dispersion is the spreading of light pulse as its travels down the length of an optical fiber. Dispersion limits the bandwidth or information carrying capacity of a fiber.

Index Terms- Optical Fibers, Dispersions, Modal Dispersions, Material Dispersion, Wave Guide Dispersions, Polarization Dispersions, Chromatic Dispersions.

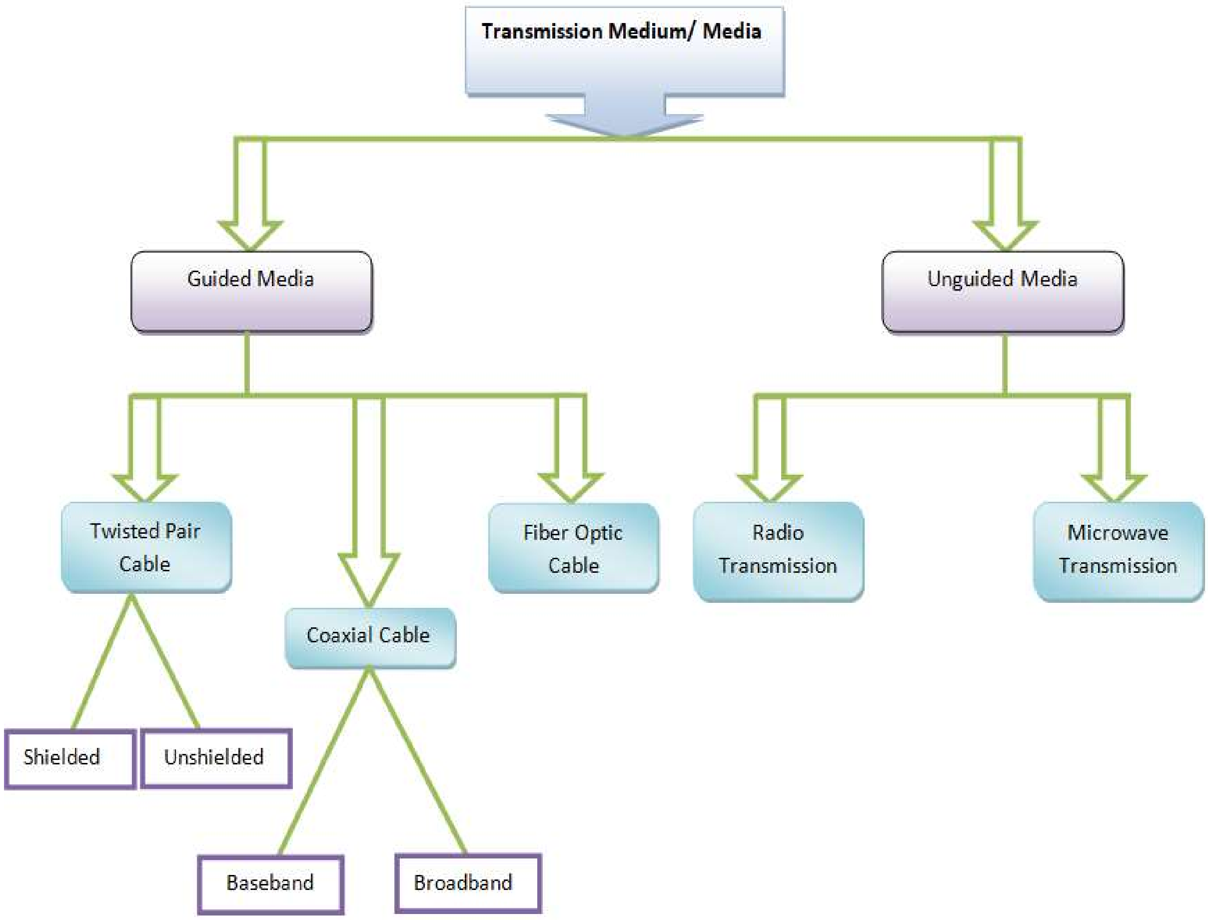
CONTENTS

INTRODUCTION

- Optical communication is a communication way with optical wave or pulses of light as carrier.
- Light wave gets easily dissipated over atmosphere, thus, optical fibers i.e. glass or plastic is used to contain and guide light waves.
- The transmission of data by fiber-optic communication is greatly affected by fiber attenuation, decay and fiber distortion. One of such losses is called Cladding Decay. Also, optical fibers have a considerably higher installation charges.
- Both in long haul and short haul installations, there arises a need for a trade-off between the quality and the cost budget.
- Traditional method for cladding decay estimation takes costly equipments which are impractical to be used for smaller installations with lower budgets.
- In this project, we use an approximation technique, called Chebyshev Approximation Technique, to determine the aforementioned loss approximately with higher precision levels.

Transmission Medium

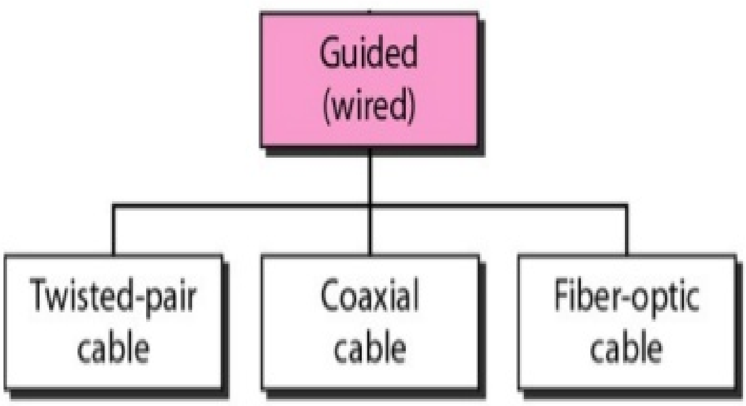
Transmission media is a communication channel that carries the information from the sender to the receiver.



Guided Media

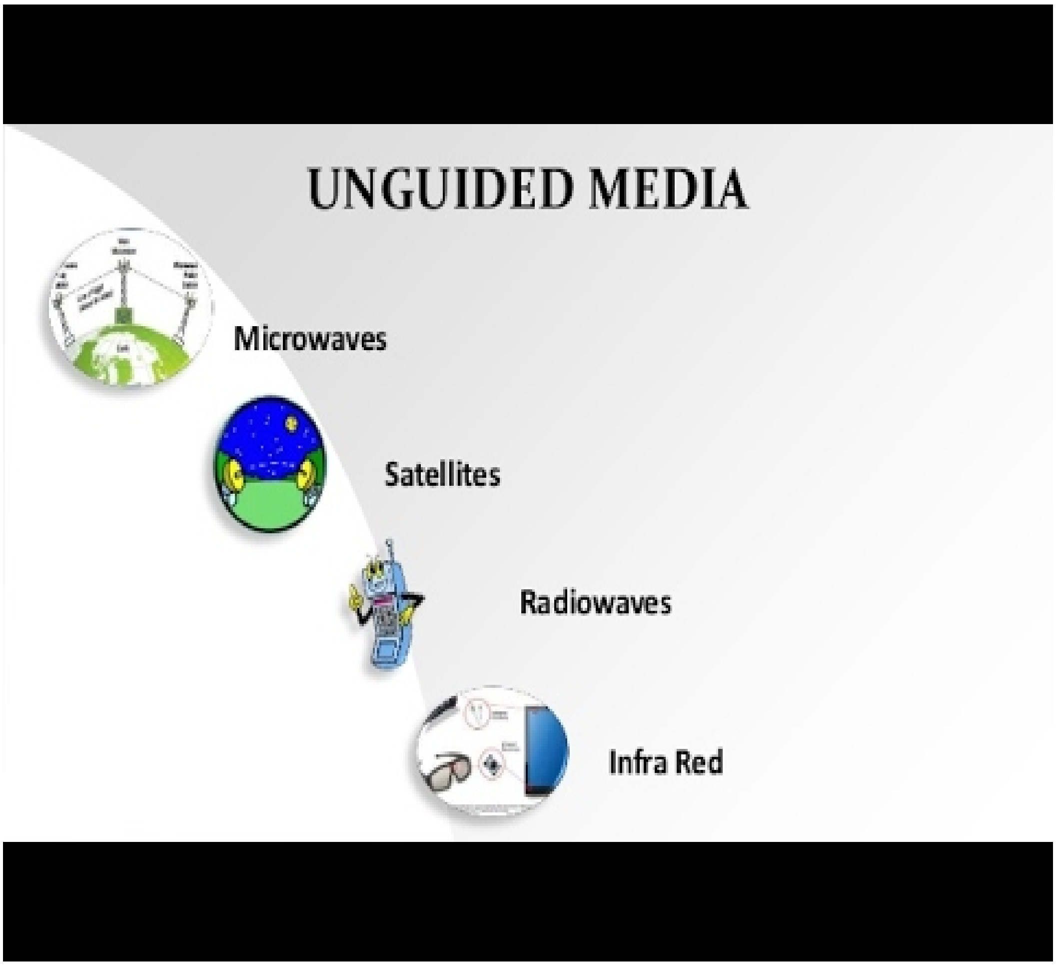
Guided media, which are those that provide a conduit from one device to another, include Twisted-Pair Cable, Coaxial Cable, and Fibre-Optic Cable.

Guided media



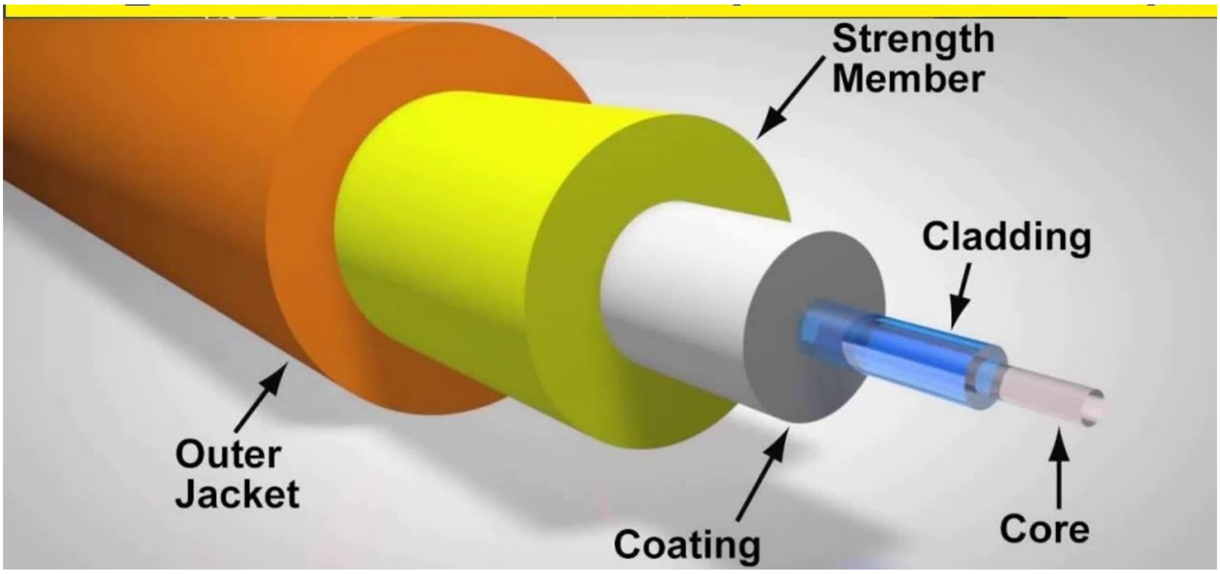
Unguided Media

Unguided medium transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication. Signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them.



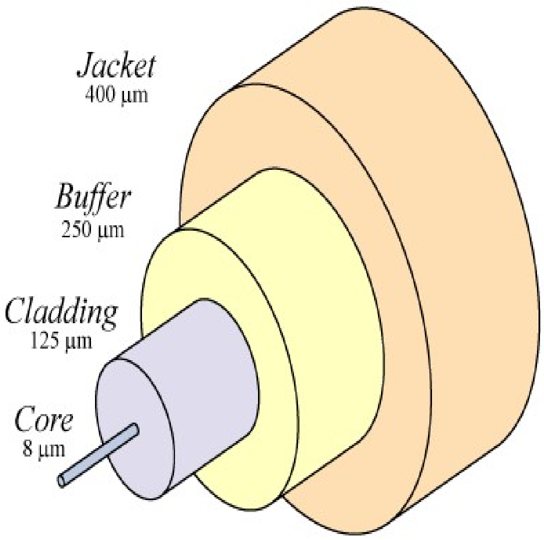
Optical Fibers

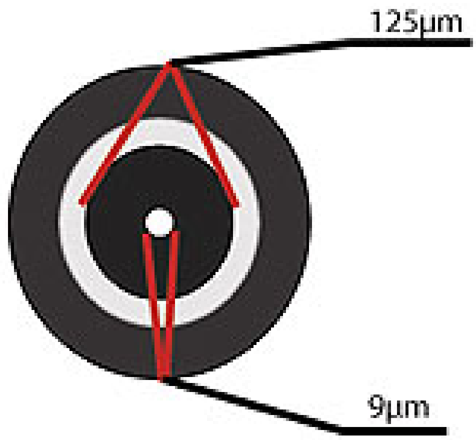
- Optical fiber is the technology associated with data transmission using light pulses traveling along with a long fiber which is usually made of plastic or glass.
- Optical fibers have an inner core of lower refractive index and outer cladding with higher refractive index.
- The fiber optical cable uses the application of total internal reflection of light.
- Optical fibers are also unaffected by electromagnetic interference.



Single Mode Optical Fibers

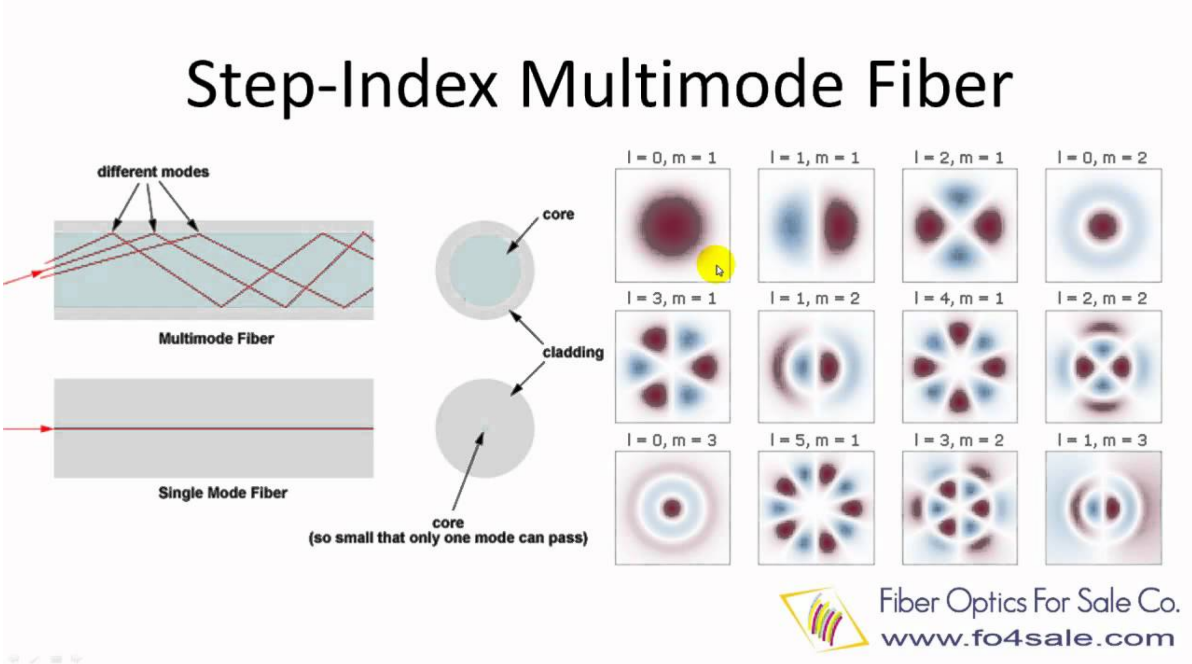
In fiber-optic communication, a **single-mode optical fiber** (**SMF**) is an optical fiber designed to carry only a single mode of light - the transverse mode. Modes are the possible solutions of the Helmholtz equation for waves, which is obtained by combining Maxwell's equations and the boundary conditions. These modes define the way the wave travels through space, i.e. how the wave is distributed in space. Waves can have the same mode but have different frequencies. This is the case in single-mode fibers, where we can have waves with different frequencies, but of the same mode, which means that they are distributed in space in the same way, and that gives us a single ray of light. Although the ray travels parallel to the length of the fiber, it is often called transverse mode since its electromagnetic oscillations occur perpendicular (transverse) to the length of the fiber.

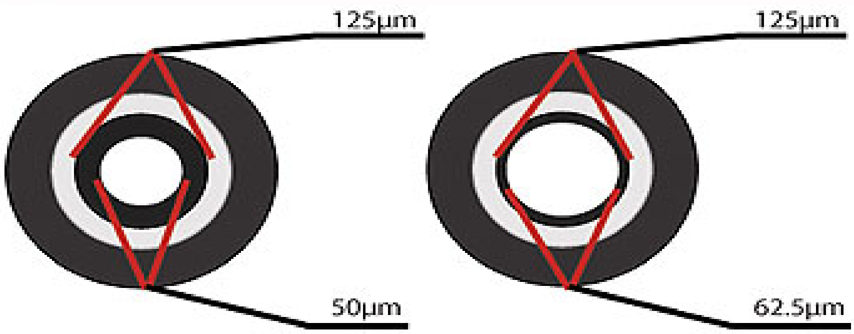




Multi Mode Optical Fibers

Multi-mode optical fiber is a type of optical fiber mostly used for communication over short distances, such as within a building or on a campus. Multi-mode links can be used for data rates up to 100 Gbit/s. Multi-mode fiber has a fairly large core diameter that enables multiple light modes to be propagated and limits the maximum length of a transmission link because of modal dispersion. Multimode fiber optic cable has a large diametral core that allows multiple modes of light to propagate. Because of this, the number of light reflections created as the light passes through the core increases, creating the ability for more data to pass through at a given time. Because of the high dispersion and attenuation rate with this type of fiber, the quality of the signal is reduced over long distances.





Step Index Optical Fibers

For an optical fiber, a **step-index profile** is a refractive index profile characterized by a uniform refractive index within the core and a sharp decrease in refractive index at the core-cladding interface so that the cladding is of a lower refractive index. The step-index profile corresponds to a power-law index profile with the profile parameter approaching infinity. The step-index profile is used in most single-mode fibers and some multimode fibers.

A step-index fiber is characterized by the core and cladding refractive indices n_1 and n_2 and the core and cladding radii a and b. Examples of standard core and cladding diameters 2a/2b are 8/125, 50/125, 62.5/125, 85/125, or 100/140 (units of µm). The fractional refractive-index change .

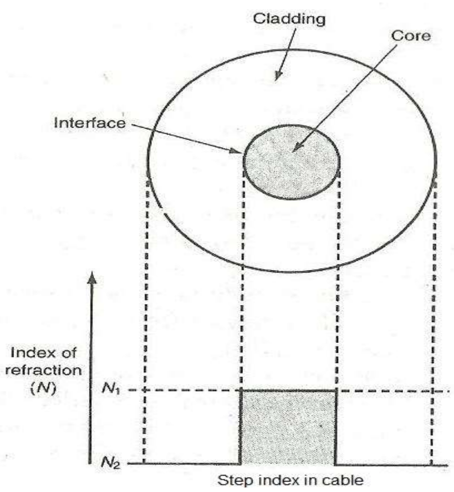
$\triangle = \frac{n_1 - n_2}{n_1} \ll 1.$ The value of n_1 is typically between 1.44 and 1.46, and Delta is typically between 0.001 and 0.02.

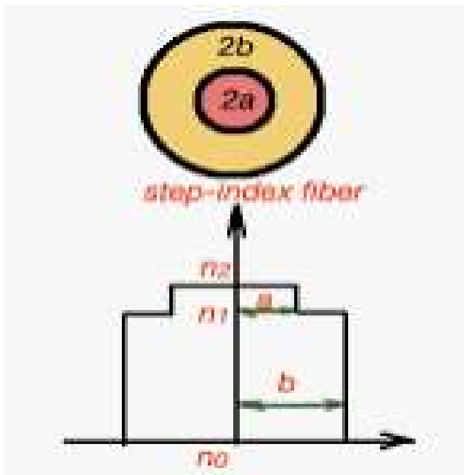
Step-index optical fiber is generally made by doping high-purity fused silica glass (SiO_2) with different concentrations of materials like titanium, germanium, or boron.Pulse dispersion in a step index optical fiber is given by

$$. = \frac{\triangle n_1 \ell}{c}$$

Where,

Delta is the difference in refractive indices of core and cladding.
n1 is the refractive index of core
L is the length of the optical fiber under observation
c is the speed of light.



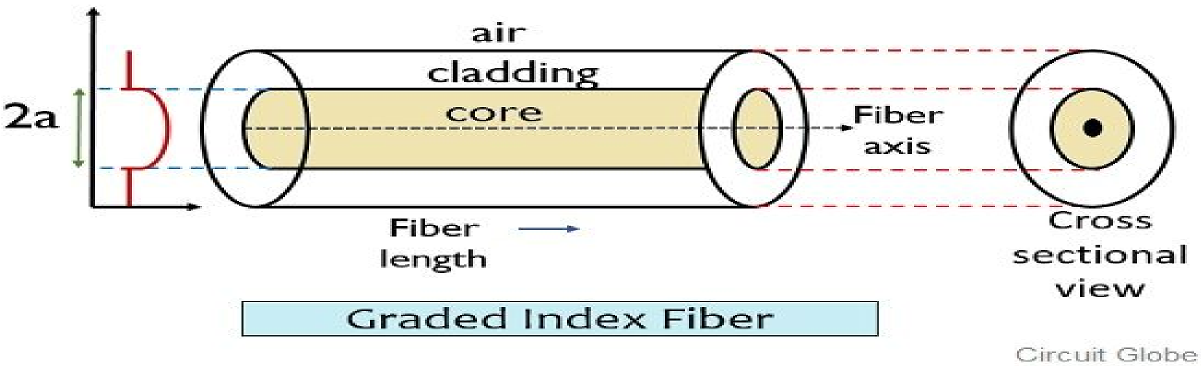


Graded Index Optical Fibers

Graded Index fiber is another type of optical fiber in which the refractive index of the core is non-uniform. This non-uniformity is present because the refractive index is higher at the axis of the core and continuously reduces with the radial movement away from the axis. However, the refractive index of the cladding is constant in the case of graded index fiber. Hence the nature of the refractive index of the core is somewhat parabolic.

Unlike graded index optical fiber, the step index fiber has a constant refractive index at the core as well as cladding.

In the figure shown below you can see graded index fiber with its index profile:



In this type of fiber, the light ray experiences refraction thus gets bent towards the core. Thereby allowing propagation of ray in a curved path.The refractive index of graded index fiber in the mathematical term is expressed as:

$$n(r) = \begin{cases} n_1 \left[1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right]^{1/2} & \text{for } 0 \leq r \leq a \\ n_1 (1 - 2\Delta)^{1/2} \approx n_1 (1 - \Delta) = n_2 & \text{for } r \geq a \end{cases}$$

a is the radius of the core

r is the radial distance from the core axis

α shows characteristic of the refractive index profile

n_1 and n_2 are the refractive indices of core and cladding respectively.

Advantages

Fiber Optics has the following advantages:

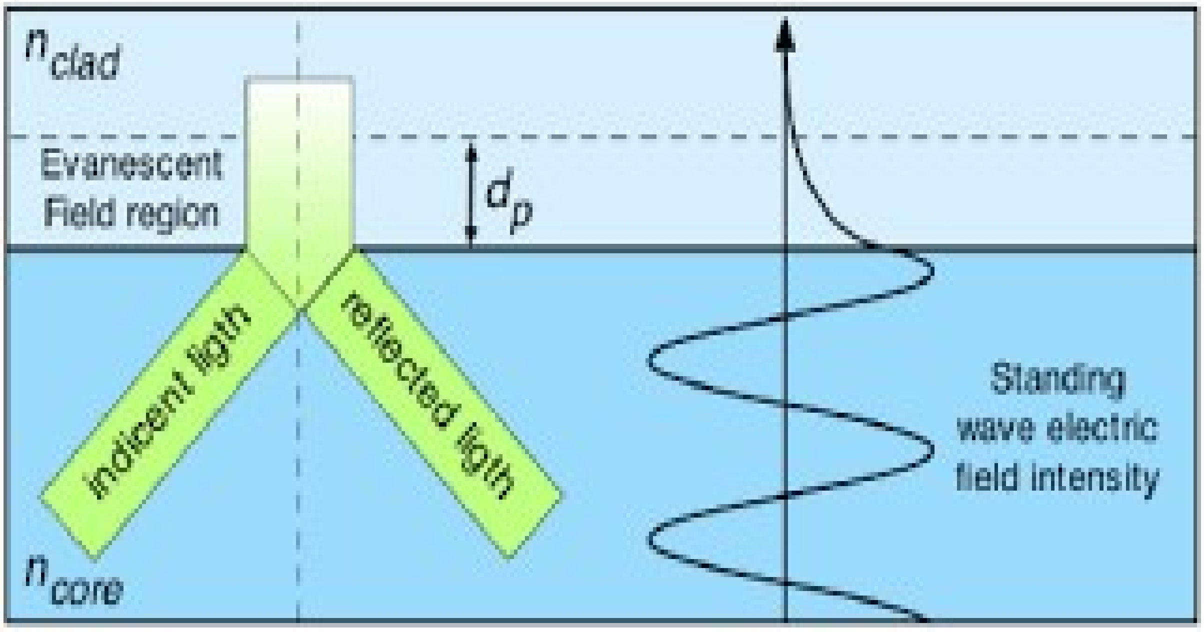
(I) Optical Fibers are non-conductive (Dielectrics).
(II) Electromagnetic Immunity:
(III) Large Bandwidth (> 5.0 GHz for 1 km length)
(IV) Small, Lightweight cables.
(V) Security.
(VI) Economical and cost effective
(VII) Thin and non-flammable
(VIII) Less power consumption
(IX) Less signal degradation
(X) Flexible and lightweight

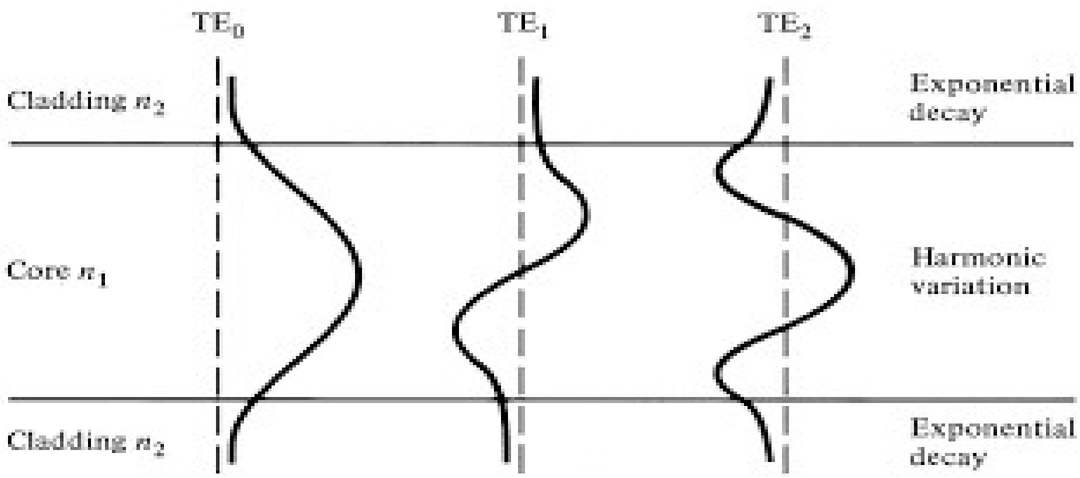
Why Single Mode Step Index Fiber is used?

- Single Mode cables can propagates signals to larger distances. Given the light source has a narrow spectral width, single mode cables can transmit higher bandwidths.
- The single-mode step index fiber has the distinct advantage of low intermodal dispersion.
- The external interferences and data dispersion is reduced that limit light scattering and reduce data loss and light waste.
- Step Index fibers are cheaper than Graded Index fibers.
- f(R) for Single Mode Step Index fibers is equal to 0. This vastly simplifies the calculations and reduces efforts.

Cladding Decay

- The cladding decay occurs when the electric field component interacts with the cladding thereby changing its optical properties, either linearly or non-linearly.
- It is one of the most vital losses that determine the usability of a particular optical fiber.





Chebyshev Approximation Technique

- It is an approximation numerical technique for solving nonlinear optimal control problems is introduced.
- This is similar to the Fourier analysis of the function, using the **Chebyshev polynomials** instead of the usual trigonometric functions. term, one gets an Nth-degree **polynomial approximating** f(x). is close to a level function with N+2 extrema, so it is close to the optimal Nth-degree **polynomial**.

- Application of this method results in the transformation of differential and integral expressions into systems of algebraic or transcendental expressions in the Chebyshev coefficients.
- Application of this method results in the transformation of differential and integral expressions into systems of algebraic or transcendental expressions in the Chebyshev coefficients.
- By solving the Maxwell's Equation with appropriate boundary conditions, we have derived the equations.

  a0 [v2 (1-f(Ri))-w 2] + a2 [4+Ri 2 (v2 (1-f(Ri))-w 2] + a4 [16Ri 2+Ri 4 (V 2 (1-f(Ri)-w 2)] + a6 [36Ri 4+Ri 6 (V2 (1-f(Ri))-w 2] = 0

  for i =1,2,3 (Chebyshev points)

  Also,

  a0 (αw+β) + a2 (αw+2+β) + a4 (αw+4+ β) + a6 (αw+6+ β) = 0

  where, a0 ,a2 ,a4 ,a6 are constants derived from solving Maxwell's Equations with proper boundary conditions

  Ri is the Radial Distance from core of the optical fiber.

Advantages:

- Low Complexity.
- Approximation technique that has helped yield results with high precision levels.
- The Approximate value is really close to the desired outcome.

Disadvantages:

- The main limitation of this project is low 'V' region (V<1.0) gives considerable amount of errors and when compared with practical experimental techniques.
- For the sake of precision, here we are bargaining with the accuracy for a single observation.

SAMPLE CODE OF THE PROJECT

Sample code for w calculation for SI with v= put value 1.6 or 1.8 0r 2.0 (LP01 mode)

```
v=value;g=0;r1=0.9749;r2=0.7818;r3=0.4338;x1=0;x2=0;x3=0;
alpha=1.034623;beta=0.3890323;
 syms w;
b=[(v^2-w^2+v^2*g*x1^2),(4+r1^2*((v^2-
w^2)+v^2*g*x1^2)),(16*r1^2+r1^4*((v^2-
w^2)+v^2*g*x1^2)),(36*r1^4+r1^6*((v^2-w^2)+v^2*g*x1^2));(v^2-
w^2+v^2*g*x2^2),(4+r2^2*((v^2-w^2)+v^2*g*x2^2)),(16*r2^2+r2^4*((v^2-
w^2)+v^2*g*x2^2)),(36*r2^4+r2^6*((v^2-w^2)+v^2*g*x2^2));(v^2-
w^2+v^2*g*x3^2),(4+r3^2*((v^2-w^2)+v^2*g*x3^2)),(16*r3^2+r3^4*((v^2-
w^2)+v^2*g*x3^2)),(36*r3^4+r3^6*((v^2-
w^2)+v^2*g*x3^2));(alpha*w+beta),(alpha*w+2+beta),(alpha*w+4+beta),(alph
a*w+6+beta)];
 D=det(b);
    w=solve(D,w)   ------------we get the linear W value for the particualr V
    value=1.6,1.8,2.0.
```

after getting W linear,using cramer we solve for A coefficients..(in linear case and get A2,A4,A6).

For nonlinearity, we take g value and then calculate modal field Ψ with A values(A2,A4,A6 as computed for linear) and R1,R2,R3.

Again we solve the 4x4 determinant and solve for W(NL case) putting g and Ψ values.

With this W(NL) value we again calculate nonlinear A values(here we use simple iteration and cramers rule) .

THIS IS THE ALGO OR LOGIC OF COMPUTATION PROCEDURE.

Sample Code for SI Fiber :- For A coefficients value

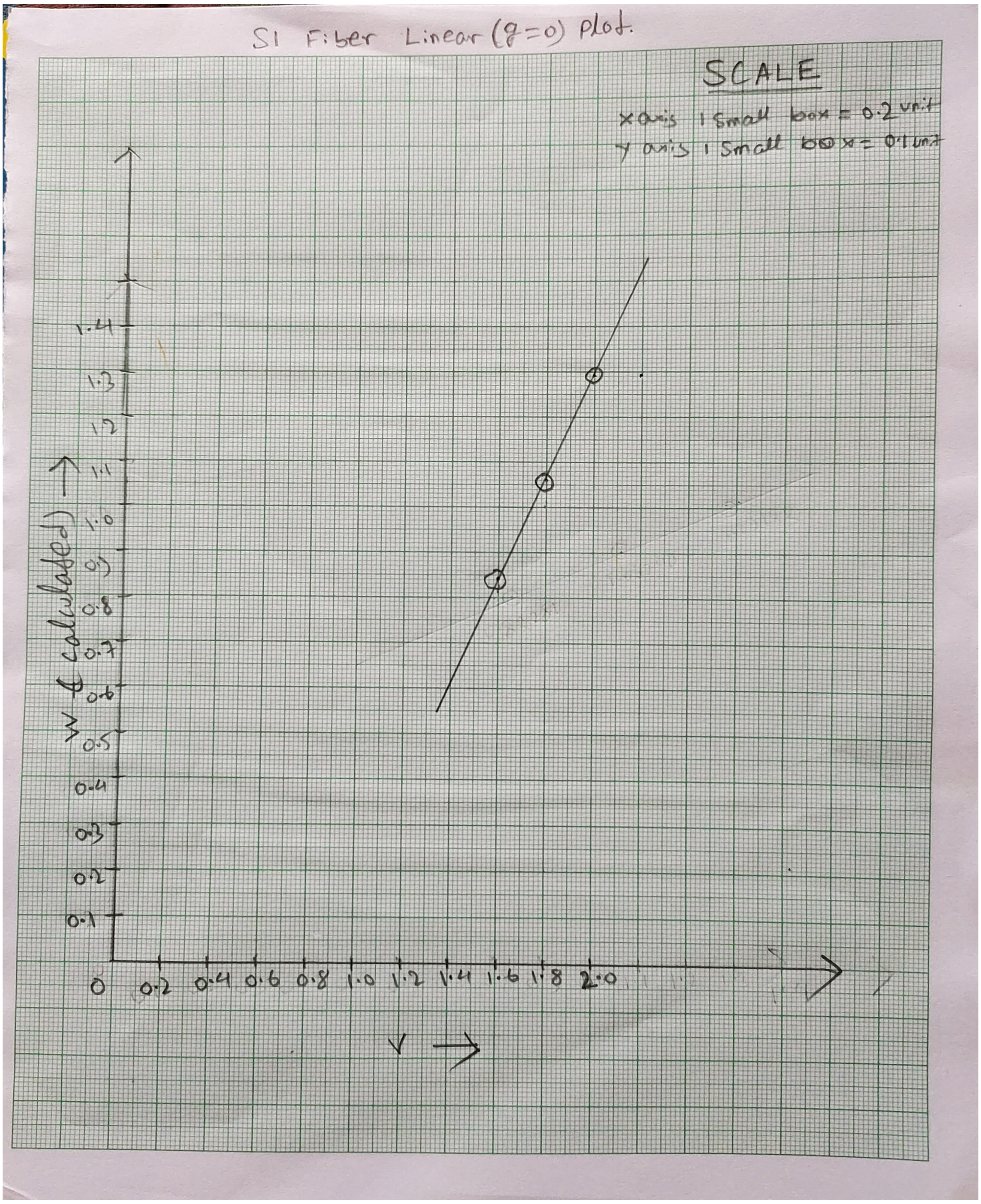
```
v=value of 1.6;w=value
;g=0.14508;r1=0.9749;r2=0.7818;r3=0.4338;a2=value;a4=value;a6=value;
x1=1+a2*(r1^2)+a4*(r1^4)+a6*(r1^6);x2=1+a2*(r2^2)+a4*(r2^4)+a6*(r2^6);x3=
1+a2*(r3^2)+a4*(r3^4)+a6*(r3^6);
b=[(4+r1^2*(v^2-w^2+v^2*g*x1^2)),(16*r1^2+r1^4*(v^2-
w^2+v^2*g*x1^2)),(36*r1^4+r1^6*(v^2-w^2+v^2*g*x1^2));(4+r2^2*(v^2-
w^2+v^2*g*x2^2)),(16*r2^2+r2^4*(v^2-w^2+v^2*g*x2^2)),(36*r2^4+r2^6*(v^2-
w^2+v^2*g*x2^2));(4+r3^2*(v^2-w^2+v^2*g*x3^2)),(16*r3^2+r3^4*(v^2-
w^2+v^2*g*x3^2)),(36*r3^4+r3^6*(v^2-w^2+v^2*g*x3^2))];
p=-(v^2-w^2+v^2*g*x1^2);q=-(v^2-w^2+v^2*g*x2^2);r=-(v^2-w^2+v^2*g*x3^2);
D=[(p),(16*r1^2+r1^4*(v^2-w^2+v^2*g*x1^2)),(36*r1^4+r1^6*(v^2-
w^2+v^2*g*x1^2));(q),(16*r2^2+r2^4*(v^2-
w^2+v^2*g*x2^2)),(36*r2^4+r2^6*(v^2-
w^2+v^2*g*x2^2));(r),(16*r3^2+r3^4*(v^2-
w^2+v^2*g*x3^2)),(36*r3^4+r3^6*(v^2-w^2+v^2*g*x3^2))];
>> det(D)/det(b);          % this is value of A2
D=[(4+r1^2*(v^2-w^2+v^2*g*x1^2)),(p),(36*r1^4+r1^6*(v^2-
w^2+v^2*g*x1^2));(4+r2^2*(v^2-w^2+v^2*g*x2^2)),(q),(36*r2^4+r2^6*(v^2-
w^2+v^2*g*x2^2));(4+r3^2*(v^2-w^2+v^2*g*x3^2)),(r),(36*r3^4+r3^6*(v^2-
w^2+v^2*g*x3^2))];
det(D)/det(b);          % this is value of A4
D=[(4+r1^2*(v^2-w^2+v^2*g*x1^2)),(16*r1^2+r1^4*(v^2-
w^2+v^2*g*x1^2)),(p);(4+r2^2*(v^2-w^2+v^2*g*x2^2)),(16*r2^2+r2^4*(v^2-
w^2+v^2*g*x2^2)),(q);(4+r3^2*(v^2-w^2+v^2*g*x3^2)),(16*r3^2+r3^4*(v^2-
w^2+v^2*g*x3^2)),(r)];
det(D)/det(b);          % this is value of A6
```

TABLE
Values for Step Index Fiber :(SI) $n_{NL}P$=+/-1.5X10^{-14}; g= +/-0.14508

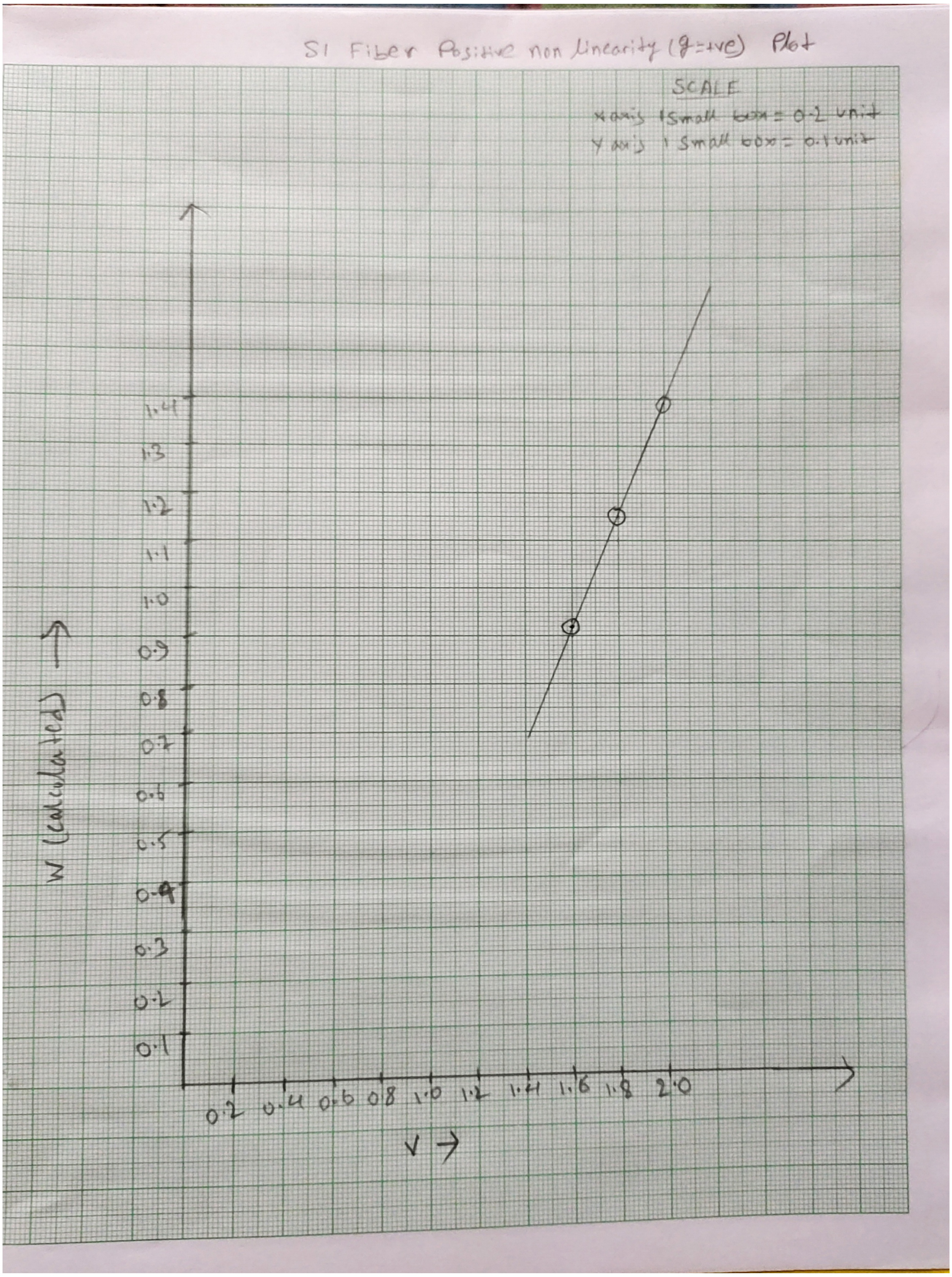
V	Condition	W calculated	A2	A4	A6
1.6	Linear (g=0)	0.83281	-0.4665	0.0542	-0.0026
	Positive Non linearity (g+ve)	0.92228	-0.5177	0.0838	-0.0082
	Negative non linearity(g –ve)	0.74009	-0.4120	0.0242	0.0028
1.8	Linear (g=0)	1.06240	-0.5276	0.0692	-0.0037
	Positive Non linearity (g+ve)	1.1598	-0.5868	0.10875	-0.011956
	Negative non linearity(g –ve)	0.96157	-0.46445	0.02886	0.004383
2.0	Linear (g=0)	1.29183	-0.5825	0.0842	-0.0049
	Positive Non linearity (g+ve)	1.3968	-0.65038	0.13491	-0.016291
	Negative non linearity(g –ve)	1.1833	-0.5098	0.03214	0.006346

GRAPHS

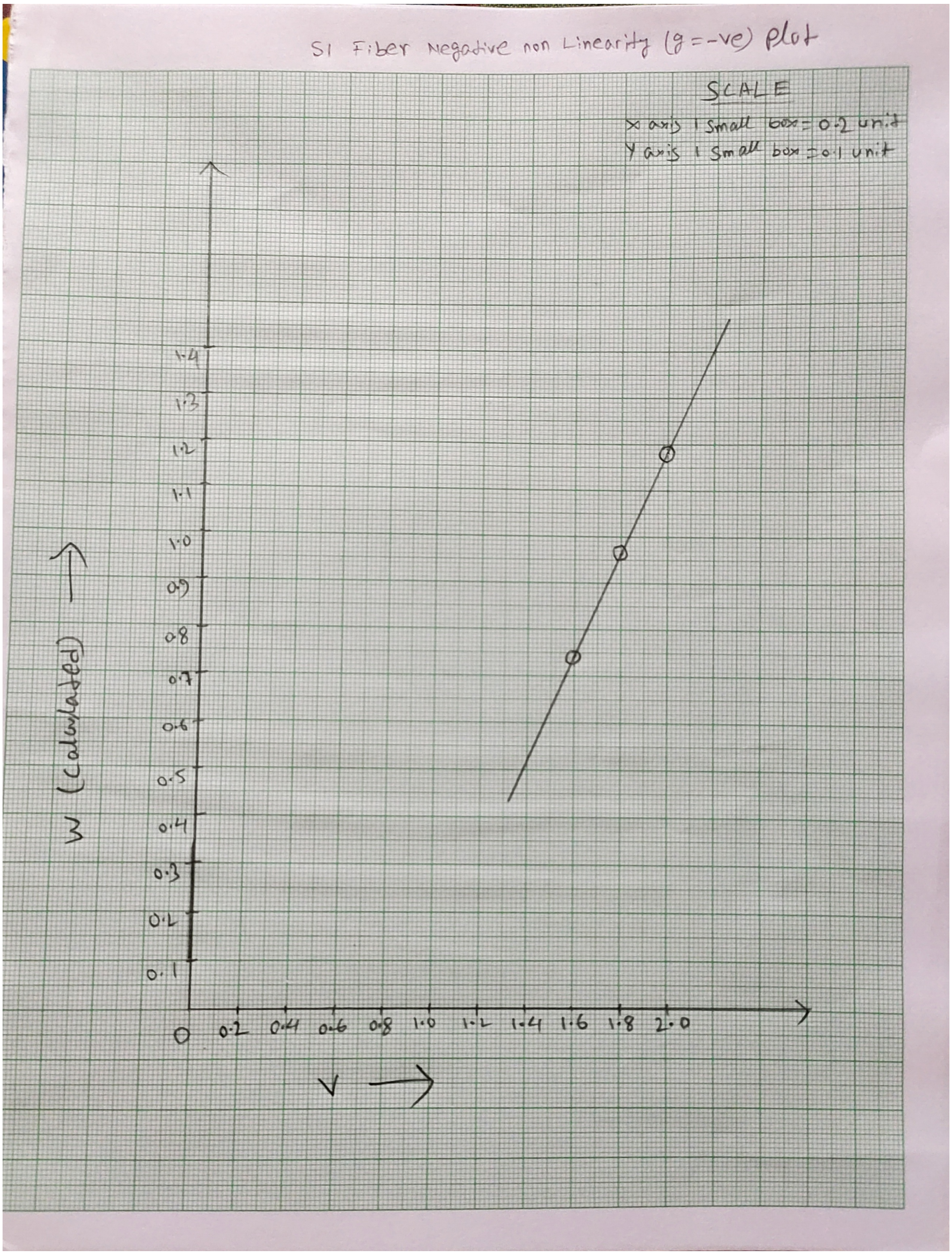
SI Fiber Linear(g=0),X-axis =V,Y axis=w



SI Fiber Positive non-Linearity (g=+ve),X-axis =V,Y axis=w



SI Fiber Negative non-Linearity (g=-ve),X-axis =V,Y axis=w



Scope of the Project

This project helps us to estimate the Cladding Decay Parameter in a much uncomplicated way using the Chebyshev Approximation Technique. This technique is much more straightforward than the orthodox methods.
Here, we have estimated the outcome for Single Mode Step Index Optical Fiber that obeys the order of Linearity.
This gives the basic foundation or framework which would help us towards estimating the Cladding Decay Parameter for fibers that do not obey linearity, i.e., losses gradually change over distance.

REFERENCES

1.Govind P. Agrawal. (2002). Fiber-optic communications systems (Third Edition). Rochester, NY: John Wiley & Sons, Inc.
2.V.S.Bagad. (2009). Optical fiber communication (First Edition). Pune, India: Technical Publications Pune.
3. Raman Amplification in Fiber Optical Communication Systems (Editors - Clifford Headley,Govind P. Agrawal)
4. http://en.wikipedia.org/wiki/Optical_fiber