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Optical Fiber communication System survey : Past , Present and Future

[1] Prince Sharma, [2]Amarjeet Kumar Ghosh

[1] *M.Tech Digital Communication, R.G.P.V, Vits, Bhopal, India,*
[2] *Assistant professor, Digital communication, R.G.P.V, Vits ,Bhopal,India,*

Abstract — *optical fiber communication is a way of sending information from one place to another by transmitting pulses of light via optical fiber. Electromagnetic carrier waveform from light are modulated to carry information. Fiber is better than electrical cable for high bandwidth, long distance or immunity to electromagnetic interference. Optical fiber is very widely used for telecom companies to transmit information signals, internet and cable television signals. In a research at Bell lab found internet speed more than 100 petabit kilometre per second using optical fiber. On April 22nd 1977 the first line telephone traffic using fiber optics at a 6Mbits/S speed in long beach California. In 2nd generation of fiber optic communication accomplished world longest commercial fiber optic network covered 3268 Km & linked 52 Community. This system were operating at 1.7 Gb/s bit rate with repeater spacing at every 50 Km. In 3rd generation fiber optic communication system the improvement bring to commercially operate at 2.5Gb per second with repeater spacing at every 100 km. In 4th generation of fiber optics communication with the use of amplifier bit rate reached to 14Tbit per second over single 160Km link. 5th generation development focus on extending wavelength range for operating WDM in optical fiber. Maintenance of bending radius for optical fiber signal propagation. The loss of signal strength which effect the integrity of data transmission is called bending loss*

Keywords*- Ofc, WDM, OFDM and Bending radius*

INTRODUCTION

In 1870, John Tyndall demonstrated that light used total internal reflection to flow a specific path by using a jet of water that flowed from one cointainer to another & a beam of light . A method of " piping light" is used for light transferred in patented in 1880 by William Wheeling. That same year, Alexander Graham bell developed a system called photophone which was an optical voice transmission system. Photophone use to carry the human voice upto 200 meter by using free space light. Specially placed mirrors reflected sunlight on to a diaphragm attached in the mouth piece of photophone other end mounted with a parabolic reflector, was a light sensitive selenium resistor and this resistor was connected to both terminal of battery which was in turn, connected to telephone receiver then spoke into the photophone, the contented diaphragm vibrated, casting varies intensity of light altered the current that passed through the receiver of telephone which then converted the light into speech.

The Twentieth century

A phenomenal rate of progress is experienced in the second half of the twentieth century with the development of the fiberscope. Fiberscope is a image transmitting device, it was first practle that all glass fiber was concurrently devised by the American optical company Brian O' Brian & Narinder kapany. Core is the innermost region of the fiber used for light transmission while coating is the coating of glass which used to prevented the light from leaking out of the core by light reflecting within the boundries of core. This is explaned by Snell's law which states that the angle at which light is reflected is dependent on the refrective indices of the two material. Cladding had lower refrective index cause the light to be angled into the core. Gordan Gould a graduate student at Columbia University popularised the use of laser he described it as a intense light source soon Charles Townes & Aurthur Schawlow supported the laser in scientific background. After several generation of laser the ruby laser and the helium-neon laser developed in 1960 and soon in 1962 semiconductor laser were first realized. High modulation frequency capacity of laser as a mean of carrying information is noticed by communication engineer. As information carrying capacity of light is 10,000 times that of highest radio frequencies being used. Hence the laser is not suitable for open air as it is adverslyaffected by environmental conditions such as smog,hail,snow & rain. In 1966 Charles Kao & Charles Hockham published a landmark paper proposing that optical fiber might be the most useful medium to transmit if anyhow its attenuation could be kept under 20 decibel per kilometre. Optical fiber exhibited loss of 1,000db per kilometre at the time of this proposal means only 1/100th of the transmitted optical power can reached the receiver. In 1970 Drs. Robert maurer, peter Schulty & Donald Keck succeeded in devloping a glass fiber which exhibited less than 20 db per kilometre attenuation. The development of the fiber optics in generations can be tied to wavelength. The earliest operating wavelength for fiber optics system were developed of about 850 nm the wavelength is so called "First window", in silica based optic fiber this wavelength regionoffers low optical loss window. This wavelength region was initially very attractive. The technology for light emitter had already been perfected in infrared LED's and in visible indicator. As technology successes this window become less attractive because of high 3 db per kilometer loss. Most companies switched at 1310 nm called " Second Window" with low attenuation 0.5 db per kilometer. The third window called at 1550 nm was developed by

Nippon telegraph and Telephone (NTT) in 1977. It offered silica based fiber optical loss about 0.2 db per kilometer. Now 850 nm,1310 nm and 1550 nm systems are deployed and manufactured with low end. Longer wavelength has its advantage that it gives higher performance, with higher cost and shortest wavelength link can be avail with lower cost. Shortest length link can be handled with wavelength 850 nm or 660 nm. " Fourth Window" called at near 1625 is developed but the loss is comparable with 1550 nm.

Fiber Optic Communication

Optical fiber communication is a way of sending information from one place to another by transmitting pulses of light via optical fiber. Electromagnetic carrier waveform from light are modulated to carry information. Fiber is better than electrical cable for high bandwidth, long distance or immunity to electromagnetic interference. Optical fiber is very widely used for telecom companies to transmit information signals, internet and cable television signals. In a research at Bell lab found internet speed more than 100 petabit kilometre per second using optical fiber.

Single Mode Cable

This cable has one mode of transmission with a single stand of glass fiber with diameter of 8.3 to 10micron. This is a narrow diameter fiber which only propagate one mode typically 1310 or 1550. It carries higher bandwidth than multimode fiber and light sourse with a narrow spectal which is required. It is also called as uni-mode fiber, single mode optical fiber and mono mode optical fiber

Multi Mode Cable

Multimode cable has a bigger diameter in comparision to single mode i.e between 50-100 micron range for the light carry component. Normally WDM is not used in multi mode fiber. Its application of POF is plastic based cable which produce similar performance as glass cable for short run, with lower cost. Multimode fiber gives high bandwidth at high speed such as 10-100 MBS gigabit , 275 to 2 Km over medium distance. Light waves have numerous path, modes to dispersed as they travel through cable. Core 850 nm or 1310 nm. Generally multimode fiber cables core diameter are 50,62.5 and 100 microns. Now for single mode fiber cable for long distance cable run i.e about 900-1000 meter.

Loose tube Cable

Lose tube cable is a design of optical cable which contain color coded plastic buffer tubes house and protection. Water penetration impedes by a gel filling compound. Buffer tube are stranded around a steel central member or a dielectric which is a anti-buckling element. Cable core uses aramid yarn, as a primary tensile strength member. Core is extruded by outer polyethylene jacket. In cause of armouring formed a steel tape corrugated around a single jacket cable with a additional jacket extrude over the armour. It is typically used for aerial installation for outside plant.

Tight- Buffered Cable

Tight buffered cable is a optical cable design where the fiber is in direct contact with buffered material. This design is useful as "jumper cables" in outside plant cable used in intrabuilding, general building. For hanging, routing and connectorization it provides a suggested cable structure to protect individual fiber. Tensile load is handled or beared totally by yarn strength member. Over the operating temperature range it gives maximum performance

Wavelength Division Multiplexing (WDM)

Wavelength division multiplexing is the technology in which multiple optical signals propagate in one fiber. In this technology optical network divide the transmission bandwidth in a fiber into many different small capacity " Channels" non overlapping bandwidth,with bit rate 2.5 – 40 Gb per second of each channel that electronic circuit can handle, in this each channel correspond to carrier wavelength different

Bandwidth

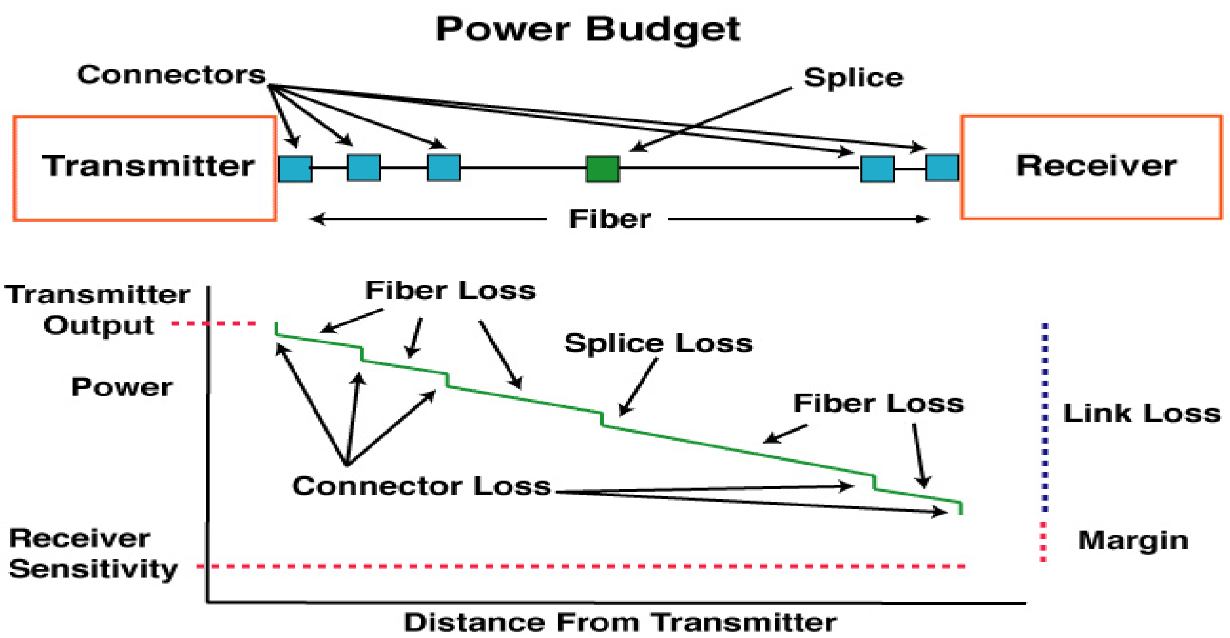
Optical fiber transmission spectrum. Fixed bandwidth is given to the fiber for each signal.guard band is introduce between two signal using adjacent bandwidth to avoid signal interference. For WDM communication transmission first convert data to a modulated optical signal than receiver convert modulated optical to data multiplexer then finally it combine multiple optical signal. Demultiplexer is the technique to differentiate signals into different carrier wavelength then router direct the signal from source to destination.

Total Link Loss Estimation

Bending radius of optical fiber communication is very important for signal propagation, excessively bent in fiber cable may refrect and escape signal through the fiber cladding. Bending may cause microbending in fiber which can permanently damage the fiber. The loss of signal strength which effect the integrity of data transmission is called bending loss.
Estimation of total path link via fiber optic where number of splices, connector and fiber length are known.

Link loss = (Fiber length * fiber attenuation/ Km) + (Splice loss * No. Of splices)+ (Connector loss* no. Of connector)

Assume 40 Km link of single mode fiber at 1310 nm with 5 splices and 2 connector pair
Link loss = (40*0.4 db/km) + (0.1*5) + (2*0.75)+3.0 db
= 21.0 db
Loss factor for single mode fiber is between 0.25 for 1550 & 0.35 for 1310 nm and for multimode fiber. 2.5 for .850 and 0.8 for 1300 nm.



BENT FIBER RADIATION LOSS
There are different ways to diagnos radiation loss of bent optical fiber. One by conformal transformation to analyse curved optical waveguides and to yield bending loss directly to approximate the non uniform waveguide by a series of linear profiles. In another method the loop of fiber is treating as a sourse of current which radiate as antenna. This is called the volume current method. Both method incorporate the change of refractive index into the calculation.

CURVED OPTICAL WAVEGUIDE ANALYSIS BY CONFORMAL TRANSFORMATION
Fiber can only support radiation mode and this radiation loss problem analyzed by conformal transformation, when the fiber is bent into loop. In this method the basic concept is to convert curved boundaries Φ in the x, y plane to straight u,vplane.
The scalar wave two- dimentional equation is
$\{ \nabla_{\chi,\gamma}^2 + K^2(x, y) \} \Psi = 0$
By replacing x,y co-ordinate system into the u, v co-ordinate system with the function f(z), for the above equation we are going to obtain the solution in the u, v coordinate system.
$W = u + iv = f(z) = f(x + iy)$
As per Cauchy Riemann relations ($\partial u/\partial x = \partial v/\partial y$, $\partial v/\partial y = -\partial v/\partial x$)
Now, $\{ \nabla^2_{u,v} + \{ dz/dw \}^2 K^2 (x(u,v0, y(u,v)) \} \Psi = 0$
We choose F(z) function to be
$F(z) = u + iv = R \ln (x + iz/R)$
In order to transform a straight one from curved waveguide.

VOLUME CURRENT METHOD

In this method a current carrying antenna to model the radiation loss of bent waveguide, in this fiber is modelled as antenna of infinitesimal thickness which radiates in a infinite medium of index equal to the cladding index. By perturbation technique volume current method is very specific to calculate the radiation loss. Loss due to small refractive index perturbation in a waveguide this method is only valid. The far field of an equivalent volume polarization. Current density by the radiation field. The induces current density in a bent fiber is

$$J = jw\Delta\varepsilon\,(r)E$$

Where

$$\Delta\varepsilon(r) = \varepsilon\,(r) - \varepsilon_1$$

The guided electric field inside the waveguide flow in same direction as polarization current. If $\Delta\varepsilon$ is non zero within the waveguide when only J is non zero, $\Delta\varepsilon$ is the difference of the dielectric constant between the core and the cladding. Polarization current also exist within the waveguide, in a straight waveguide $\Delta\varepsilon$ not equal to zero. The radiation field cancel each other in far field of a straight waveguide, the waveguide does not radiate. Because of geometric perturbation radiation is processed in a bent optical fiber , polarization current density inside the core the radiation problem of bent fiber is solved. Inside the core the polarization current density is a function of x,y,z as the variation of dielectric constant , due to bending inside the core and the internal stress.
Vector potential A in Lorenz gauge is used to solve the radiation problem of the wave A is the radiation field is defined as

$$A\,(r) = \mu_o/4\pi\ (\ e^{-jkr}/r\ ) \int_v dVJ\,(r')\, e^{jk(\ r \cdot r')} \qquad r$$

By integing the Poynting's vector S over an enclosing surface finally the total power loss is obtain

$$P_r = \int_\Omega (S.\ \hat{r}r^2\ )d\Omega$$

As the difference of dielectric constant between the core and cladding increases the total radiated power increases, the attenuation factor depends on both P radiation and P (0)

RESULT

As per measurement bending loss of fiber fully dependent on radius of curvature. The bending orientation and the direction of polarization along the fiber when the bending orientation θ , equal to zero and the polarization of the wave is along the major axis, power attenuation is minimized.
Formula for calculating bending loss

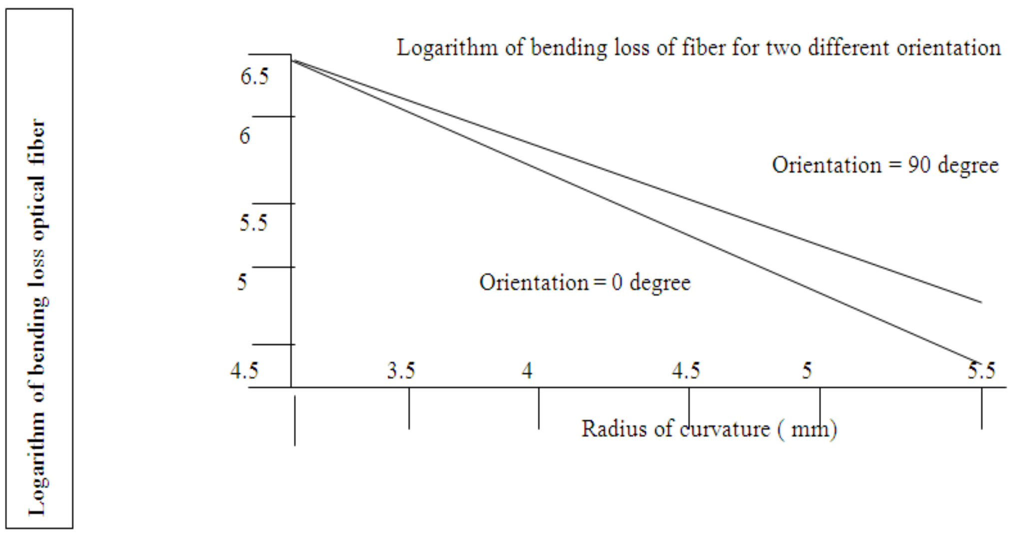
-10/L log (P out/ P inp)

As bending loss is related to the attenuation factor Ψ of the curved fiber

So -10/L log (P out/ P inp)

= 10 log (e) Ψ = 4.343 Ψ

The attenuation factor is on exponential function of the radius curvature. It gives linear function of radius of curvature, when take the algorithm of the bending loss. In extraction of curve of the algorithm of bending loss when θ is equal to 0and 90 degree which is shown in graph below.



For single mode fiber radiation loss, the slab waveguide is not a good model, also the difference of dielectric constant between the core and cladding & the radius of core are the dependant factor for bending loss . Although the change of dielectric constant inside the core on incorporate with matrix method into the calculation of bending loss but it only model fiber as a two dimensional waveguide, Now to estimate bending loss of single mode fiber use the volume current method for more precise result. Finally the implementation of optical time domain reflectometer easier, accurate and widely used in telecom communication industry to diagnose all type loss in optical fiber cable, result of OTDR is shown below. For field execution practice simply the allowed bending for signal propagation the radius not less than 15 time the cable diameter.

OTDR TRACE WITH BENT

Print date : 04/11/2016 02:41 pm | File : Fiber96f004_1550_EO.sor.pdf

Cable Id : 96f	**Fiber Id :** 4
Location A : 0167	**Location B :** 0312
Job Id :	**Operator :** dhiraj yadav

MTS 2000 (S/N 14276)	4136 RMPs (S/N 19481)	Date : 04/11/2016 02:40 pm

Setup							
OTDR	1550nm	100ns	20km	2.5m	10.0s	1.46800	-81.0 dB

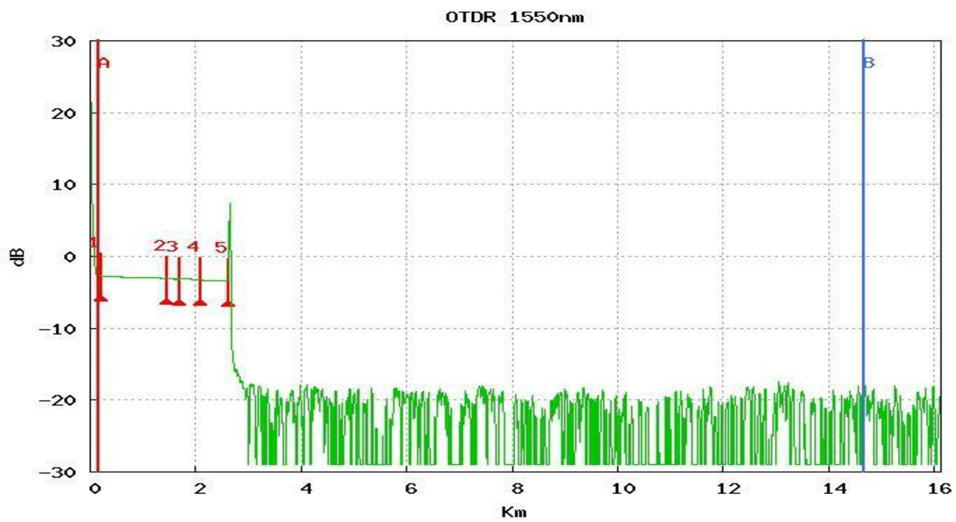
Alarms

Thresholds	None

Summary

Filename	Laser nm	Link Loss dB	Link Orl dB	Fiber End Km	Direction	Event	Alarms
Fiber96f004_1550_EO.sor	1550	0.850	51.05	2.634	0167 <- 0312	5	

A : 0.158Km -2.623 dB
B : 14.665Km -17.883 dB **A-B : 14.507Km 1.052 dB/Km** **15.260 dB**



Event	Distance	Loss	Reflect.	Slope	Section	T. Loss
	Km	dB	dB	dB/km	Km	dB
1	0.204	0.140			0.204	0.041
2	1.460	0.075		0.233	1.256	0.475
3	1.698	-0.059		0.139	0.237	0.584
4	2.103	0.128		0.255	0.406	0.628
5	2.634		-37.39	0.086	0.531	0.850

OTDR TRACE WITH NO BENT

Print date : 04/11/2016 02:53 pm

File : Fiber96f020_1550_EO.sor.pdf

JDSU

Cable Id : 96f

Fiber Id : 20

Location A : 0167

Location B : 0312

Job Id :

Operator : dhiraj yadav

MTS 2000 (S/N 14276) 4136 RMPs (S/N 19481) Date : 04/11/2016 02:53 pm

Setup

OTDR	1550nm	100ns	20km	2.5m	10.0s	1.46800	-81.0 dB

Alarms

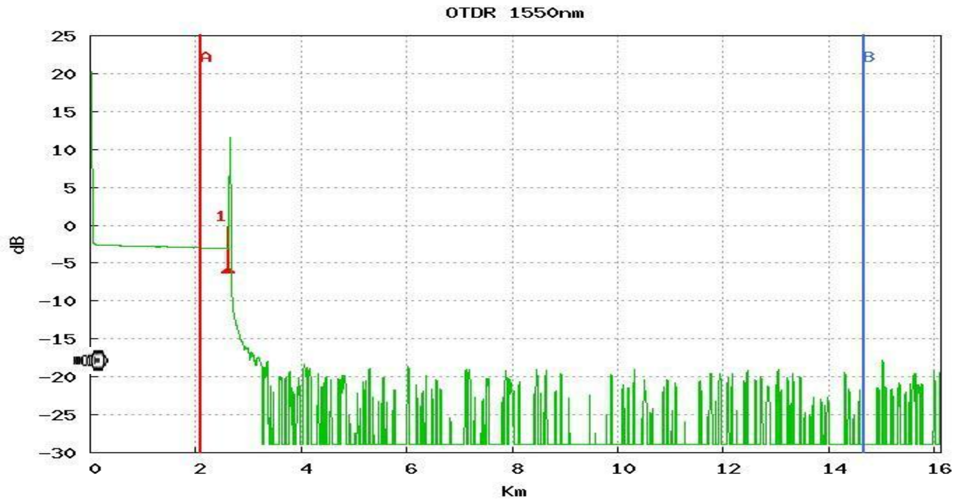
Thresholds None

Summary

Filename	Laser	Link Loss	Link Orl	Fiber End	Direction	Event	Alarms
	nm	dB	dB	Km			
Fiber96f020_1550_EO.sor	1550	0.506	41.82	2.632	0167 <- 0312	1	

A : 2.098Km -2.983 dB

B : 14.665Km -21.392 dB A-B : 12.567Km 1.465 dB/Km **18.409 dB**



Event	Distance	Loss	Reflect.	Slope	Section	T. Loss
	Km	dB	dB	dB/km	Km	dB
1	2.632		-29.56	0.192	2.632	0.506

CONCLUSION

Optical fiber communication is a way of sending information from one place to another by transmitting pulses of light via optical fiber. Electromagnetic carrier waveform from light are modulated to carry information. Fiber is better than electrical cable for high bandwidth, long distance or immunity to electromagnetic interference. Optical fiber is very widely used for telecom companies to transmit information signals, internet and cable television signals. In a research at Bell lab found internet speed more than 100 petabit kilometre per second using optical fiber. On April 22nd 1977 the first line telephone traffic using fiber optics at a 6Mbits/S speed in long beach California. **In Second generation of fiber optic communication** – Sasket a Canadian service provider accomplished construction of the world's longest commercial fiber optic network, covered 3268 Km and linked 52 communities. Till 1987 fiber optics system were operated at 1.7 Gb/S bit rates with repeater spacing at every 50 KM. **In Third generation of fiber optic communication** – difficulties are overcome by limiting the laser spectrum to a single longitudinal mode or by using dispersion shifted fibers designed to have minimal dispersion at 1.55micro meter. These improvement bring third generation system to commercially operate at 2.5 GB per second with repeater spacing at every 100 Km. **In Fourth generation fiber optic communication system** – In this wavelength division multiplexing is used to increase data capacity and optical amplification to reduce the requirement of repeaters. These two important improvement given revolutionary result in doubling of system capacity in every six months started from 1992 and bit rate of 10 TB per second reached by 2001. By using amplifier in 2006 bit rate reached to 14Tbit per second over single 160 km line.
In fifth generation development in fiber optic communication system – focusing on extending wavelength range for operating WDM system . C band is known as conventional wavelength window cover the wavelength range 1.53-1.57 micro meter and dry fiber has a low loss window promising an extension of that range to 1.30-1.65 micro meter.
Maintenaning bending radius of optical fiber communication is very important for signal propagation,excessively bent in fiber cable may refract and escape signal through the fiber cladding. Bending may cause micro bending in fiber which can permanently damage the fiber. The loss of signal strength which effect the integrity of data transmission is called bending loss. The bending loss investigation of optical fiber useful to coherent optical communication and optical sensing system. The bending loss of optical fiber very depend on radius of curvature, the direction of polarization of the wave and the orientation of bending. Elliptical cladding cause internal stress which increase the difference of refractive index between the cladding and core also confined more power in core result bending loss smaller. The refractive index profile of fiber is changed by the bending induced stress into a tilted step profile. The waveguide effective refractive index profile become less radiative than that of a uniform steps waveguide . Experimental result provide the trends of bending loss. The bending loss is minimized when the plan of curvature and the major axis of the elliptical cladding lies in same direction with the direction of polarization. However the plane of curvature is perpendicular to the direction of polarization the bending loss is maximum. The bending loss difference between two cases of bending orientation (θ equal to 0 degree or θ equal to 90 degree) for bending radius different range from order of 10^3 to the order of 10^6 db /km. the difference increases with the decrease with the radius of curvature. Stress along the Z axis and X axis are function of 1/R and $1/R^2$ respectively the photoelastic effect increase when change of refractive index as the decrease in bending radius. The bending induced stress is dominate the bending loss at small radii of curvature. Therefore bending radius decreases with the increase in the difference of bending loss.

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