Optical Fiber

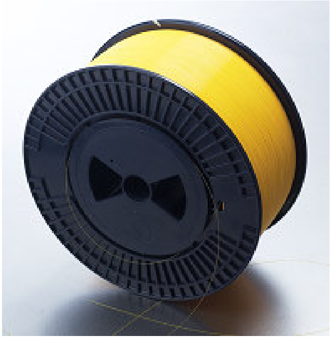
Whitepaper

A New Design Concept of Optical Fibers to Reduce Non Linearity and Bend loss in Optical Networks

Author
Reena Harnal, Saurav Dutta

Abstract

Fiber with an Enhanced value of SBS threshold and low macro bend Loss is presented in this paper. The fiber has a SBS threshold value greater than 12 dBm and complies G.657A ITU-T specification for Bend loss. It can be used as a single line fiber in Optical networks.



Keywords
SBS, Bend Loss

INTRODUCTION

Stimulated Brillouin scattering is a dominant nonlinear process in optical networks. In long haul transmission systems, it degrades the output signal once input power reaches above a certain threshold [1]. In FTTH networks bend loss is the main concern because of the stringent indoor wiring requirements. Therefore there is a requirement of an optical fiber, which has an enhanced SBS threshold value and improved bend performance. Such a fiber can be used in different parts of the optical network, in long haul and access networks, as a single line fiber.

STIMULATED BRILLOUIN SCATERRING AND BEND LOSS

Stimulated Brillouin scattering and Bend loss are the two fundamental effects which effect the signal transmission in optical networks. The below sections describes the principle behind Stimulated brillouin scattering and Bend loss.

Stimulated Brillouin scattering

Scattering is a general physical process whereby some form of radiation, such as light, sound, or moving particles, is forced to deviate from a straight trajectory by one or more localized non-uniformities in the medium through which it passes. When the optical power is such that the optical properties of the system are unmodified by the presence of the incident light beam, we refer to the scattering process as *spontaneous* or *linear*. The linear or spontaneous Scattering effect arises due to thermal fluctuations in the medium. In contrast when the fluctuations within the medium are induced by the presence of the optical field the scattering process is referred to as *stimulated or nonlinear.* In optical fibers there are various nonlinear effects namely stimulated Brillouin scattering (SBS), stimulated Raman scattering (SRS), self phase modulation (SPM), cross phase modulation (CPM) and Fourier wave mixing (FWM). The easiest of the nonlinearity to trigger is the stimulated Brillouin scattering. Light traveling through glass interacts with acoustical vibration modes [1]. This reflects the light back towards the source. Once the input power reaches some critical value, the amount of backscattered power increases quickly, with the input power. When the fiber is long enough, the backscattered power keeps increasing along the fiber in an avalanche-like process and can use most of the input optical power. Thus in this process the signal gets noisy and hinders not only the optical networks but also the instruments that tests components or system with long fiber.

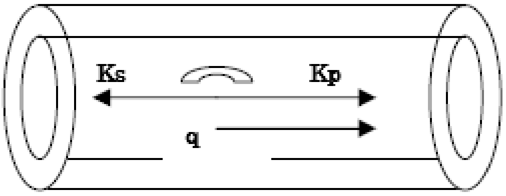


Fig 1. Principle of SBS

The physical process behind Brillouin scattering is the tendency of materials to become compressed in the presence of an electric field-a phenomenon termed electrostriction [1]. For an oscillating electric field at the pump frequency Wp, this process generates an acoustic wave at some frequency W. Brillouin scattering can be viewed as scattering of the pump wave from this acoustic wave, resulting in creation of a new wave at the pump frequency Ws.
The scattering process must conserve both the energy and the momentum. The energy conservation requires that the Stokes shift satisfy
W = Wp - Ws (1)
and the momentum conservation requires that the wave vectors satisfy
ka = kp – ks (2)
where *ka* or q is the acoustic wave vector (Fig.1). Using the dispersion relation |*ka*| = W/ na where na is the acoustic velocity, this condition determines the acoustic frequency.
W = |*ka*| na = 2na |*kp*| sin(q/2)
where |*kp*| » |*ka*| was used and q represents the angle between pump and scattered waves. In single-mode fibers, light can travel only in the forward (q =0) and backward (q =p) directions. As a result, SBS occurs in the backward direction with a frequency shift.
Wb = 2na |*kp*| (3)
Since *kp* = 2p n/ lp where lp is pump wavelength and n is mode index the *Brillouin shift* is given by
vb = Wb/2p = 2nna/lp (4)
Using na =5.96 km/sec, n=1.45 as typical values of silica fibers, vb = 11.1 GHz at lp = 1.55 µm. Equation 4 shows that vb is inversely proportional with lp. Once the scattered wave is generated spontaneously, it beats with the pump wave and creates a frequency component at the beat frequency Wp - Ws , which is automatically equal to the acoustic frequency W . As a result, the beating term acts as source that increases the amplitude of the sound wave, which in turn increases the amplitude of the scattered wave, resulting in a positive feedback loop. SBS has its origin in this positive feedback, which ultimately can transfer all power from the pump to the scattered wave. The Brillouin gain gB has a lorentzian spectral profile shape and the peak value of the gain occurs at W = Wb which depends upon various material parameters such as density and elasto-optic coefficient. The SBS threshold power
Pth satisfies the relation
gB Pth Leff /Aeff » 21 (5)
Where Leff is the effective interaction length defined as
Leff = [1-exp(-aL)]/L (6)
a represents fiber losses and Aeff = pw*w ,where w is the spot size of the fiber. *P*th can be as low as 1 mW depending on the values of *w* and a. Once the power launched into an optical fiber exceeds the threshold level, most of the light is reflected backward through SBS. Clearly, SBS limits the launched power to a few mill watts because of its low threshold.

BEND LOSS

Radiative Losses occur whenever an optical fiber is subjected to extrinsic perturbations like bend of finite radius of curvature and such losses are called Bend loss. An optical fiber can be subjected to two types of bends a) random microscopic bends of the fiber axis for example, that may occur when a fiber is sandwiched between two sand-papers b) macroscopic bends that have large radii compared to the fiber diameter, for example, that may occur during the fiber cabling and laying of the fiber cable. There are two main contributions to overall Macro bend loss: Transition loss and Pure bend loss. Transition loss appears at both the beginning and end of a curved waveguide, because of the mismatch in the fields of the straight and bent waveguide due to the abrupt change in curvature as shown in Fig 2. The predominant effect of curvature on the fundamental mode is to shift the peak of the field distribution radially outwards by a certain distance from the fiber

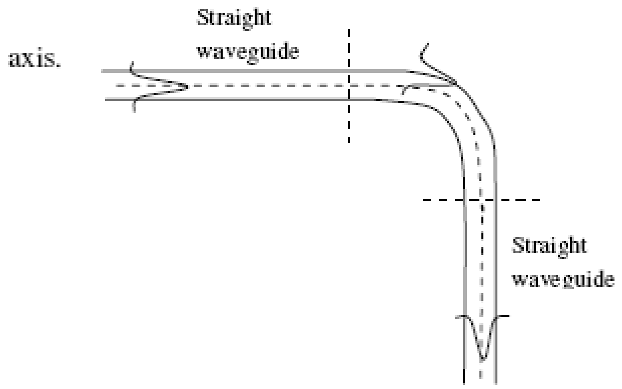


Fig 2. Illustration of the fundamental mode field mismatch between the straight and bent waveguide.

The second mechanism of loss is the actual transmission loss suffered due to radiation from side of the bent fiber. Any bound mode has an evanescent tail in the cladding, which decays almost exponentially with distance from the core- cladding interface. Since the evanescent tail moves along with the field in the core, part of energy of a propagating mode travels in the fiber cladding. In a straight fiber of arbitrary profile, the modal field at every point in the cross-section propagates parallel to the fiber axis with the same phase velocity, so that the planes of constant phase are orthogonal to the axis. However, if the fiber is bent into a planar arc of constant radius, as shown in Fig 3, it can be intituitively seen that the fields and phase fronts rotate about the center of curvature of the bend with constant angular velocity. Consequently, the phase velocity parallel to the fiber axis must increase linearly with the distance from the center of curvature of the bend. Thus, the evanescent tail on the far side of the center of curvature must move faster to keep up in phase with the field with the core. At a certain distance critical distance Rc from the center of the fiber, the portion of the evanescent tail would have to move faster than the speed of light in the fiber cladding to keep up with the core field. Since this is not possible as per fundamental laws of nature namely constant speed of light in a given medium, the optical energy in the evanescent tail beyond Rc radiates away.

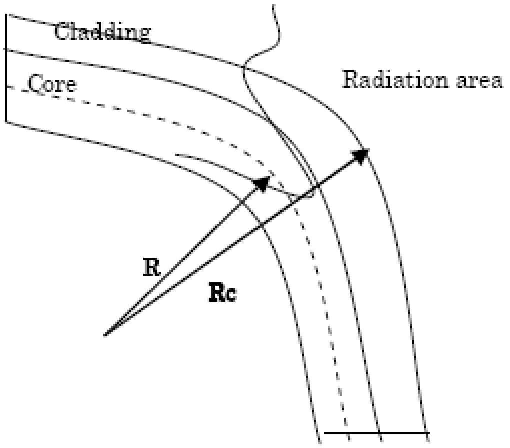


Fig 3. Schematic of the fundamental mode field on a bent waveguide, showing the oscillatory behaviour in the cladding beyond the radiation caustic.

In ITU-T G.657 recommendation [3], the characteristics of bend insensitive single mode fiber and cable for the access networks are mentioned. The following table shows the MFD range and bending properties of G.657 class A compliant bend insensitive single mode fiber.

Table 1-Class A: G.657 Attributes

Attribute	Detail	Value	
MFD	Wavelength	1310 nm	
	Range of nominal values	8.6-9.5 µm	
	Tolerance	±0.4 µm	
Bend loss	Radius (mm)	15	10
	Number of turns	10	1
	Max. at 1550 nm (dB)	0.25	0.75
	Max. at 1625 nm (dB)	1.0	1.5

SBS threshold – Measurement and Test set up

SBS threshold – It is defined as that input power at which transmitted light becomes equal to backreflected light. The SBS threshold was measured using the setup as shown in Figure 4. The measurement setup was based on an Agilent 8164A Lightwave Measurement System consisting of 81662A DFB laser at 1550 nm, a 4x1 switch and a power meter. The narrow linewidth 1550 nm optical radiation from the DFB laser was attenuated and then amplified using an Erbium Doped Fiber Amplifier (EDFA) module. The transmitted power from the test fiber, the backreflected power extracted through the circulator, and the input reference power from the tap coupler were all connected to a 4x1 switch. The output of the switch was connected to a calibrated power meter, thereby enabling all the power measurements to be done without manual intervention.

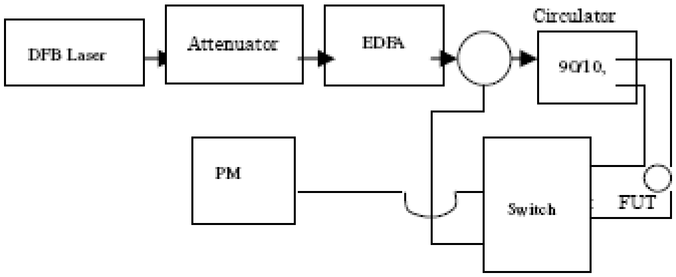


Fig 4. SBS threshold measurement set up

PROFILE DESIGN

Stimulated brillouin scattering takes place because of the interaction between the optical and the acoustic modes. As the coupling between the optical mode field and the acoustic mode fields increases, more optical power is undesirably reflected opposite to the direction of optical signal transmission. The coupling between the optical and acoustical modes is reduced via changing the refractive index profile of the core region of the optical fiber and bend property of the fiber is improved by introducing the depressed clad region. The coupling between the optical and acoustical mode is disturbed by dividing the core segment into three zones. In a segmented core optical mode field remains extended while acoustical mode field becomes more tightly confined and thus the coupling is disturbed. The three core regions are circumferential to the other, one being at the center, again there is a depressed cladding surrounding the outer core. The depressed cladding is surrounded with pure silica cladding to make up the clad. The fiber has better bend properties as compared to single mode fiber because of the depressed clad region. Figure 5 shows a cross sectional view of profile design of optical fiber. The designing is done as per the following equation 7.

$n1 > n2 > n3 > n5 > n4$ (7)

Wherein n1 is refractive index of inner sub-core region, n2 is refractive index of outer sub-core region- I, n3 is refractive index of outer sub-core region-II, n4 is refractive index of inner sub-clad region and n5 is refractive index of outer sub-clad region. According to this embodiment, the inner sub-clad region is depressed clad having refractive index lower than outer sub-clad region. The thickness of each sub-core region as shown in figure 5 is related by equation 8. $t3 > t2 > t1$ (8) Wherein t1 is thickness of inner sub-core region (11) which is equivalent to its radius, t2 is thickness of outer sub-core region-I (12) which is equivalent to difference of its radius minus radius of inner sub-core region (11) and t3 is thickness of outer sub-core region-II (13) which is equivalent to difference of its radius minus radius of inner sub-core region (11) and radius of outer sub-core region-I (12) .

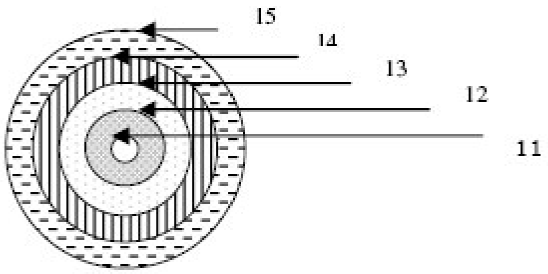


Fig 5. Cross-sectional view of the profile design

MANUFACTURING

The fiber with an enhanced value of SBS threshold and reduced bend loss can be made by any of the manufacturing techniques, which are generally used for the making of the fiber. The refractive index profile of the fiber is made by taking into number of consideration, which includes the properties of the single mode fiber such as mode field diameter, zero dispersion wavelength, cut off wavelength & attenuation of the fiber. It was ensured that the fiber has the same mode field diameter tolerance as that of single mode fiber so that there will be no splicing loss. The core region of the fiber was fragmented into several zones to achieve a higher SBS threshold value and effective area of the fiber at a particular wavelength, which is greater than the conventional single mode fiber.

RESULTS

The fiber thus obtained with the specified profile shape has characteristics similar to ITU G.652 series of the fiber. The typical values of the optical fiber.

TABLE 2: Optical parameters		
MFD	µm	9.48
Cut off lambda	Nm	1286.0
Zero dispersion λ	Nm	1324.0
Slope @ ZDW	ps/nm^2-km	0.092
Attn 1310	dB/km	0.34
Attn 1550	dB/km	0.20
SBS Pth @1550	DBm	12.0

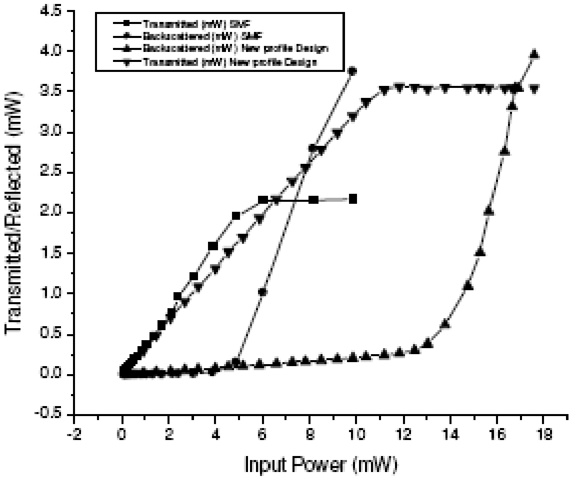


Fig 6. A comparison of SBS threshold value of the newly designed fiber with the conventional SMF.

The SBS threshold of the newly designed optical fiber is 12 dBm as compared to 7 to 8 dBm in conventional SMF. An increase of 5 dBm in SBS threshold is achieved over conventional SMF. The below table shows the bend property of the fiber which complies G.657A bend loss specification

TABLE 3: Measured Bend loss values of fiber					
S.no	R=10 mm 1 turn		R =15 mm 10 turns		Grade
	1550	1625	1550	1625	
Fiber1	0.237	0.688	0.023	0.126	G657A
Fiber2	0.24	0.743	0.026	0.128	G657A
Fiber3	0.237	0.633	0.021	0.124	G657A

CONCLUSIONS

We have developed an optical fiber, which has high SBS threshold value as well as better bend property as compared to conventional single mode fiber. The fiber thus developed can be used as a single fiber in optical networks. It can be used as a feeder fiber in long haul networks and as a terminator fiber in access networks.

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Sterlite Technologies Limited

Aurangabad
Bangkok
Beijing
Boston
Haridwar
Johannesburg
Dadra
London
Moscow
Mumbai
New Delhi
Piparia
Pune
Rakholi
Shanghai

Phone: +91-20-30514000
communications@sterlite.com

www.sterlitetechnologies.com