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Maximizing Optical Power Throughput in Long Fiber Optic Links

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Maximizing Optical Power Throughput in Long Fiber Optic Links

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EXECUTIVE SUMMARY

- This report provides a guide for designing high bandwidth fiber optic links capable of delivering high optical power to the output.
- Application for high optical power fiber optic links include antenna remoting, high dynamic range true time delay lines, and optoelectronic oscillators.
- Outlined here are the design considerations for maximizing optical power throughput in long fiber optic links.
- This report presents theoretical equations for bandwidth limitations caused by chromatic dispersion and optical power limitations caused by stimulated Brillouin scattering.
- The application of the described design considerations is demonstrated through the construction and testing of a 20.4 km link.

1 INTRODUCTION

Analog fiber optic links are employed in applications such as antenna remoting, cable TV distribution, and true time delay applications. These fiber links offer the advantage of a relatively low loss over a distance of hundreds of meters or several kilometers. To maintain a high dynamic range in these systems, it is desirable to have as much low noise optical power as possible at the output of the link [1]. Although high power lasers are available to overcome the intrinsic loss of standard single mode optical fibers (0.2 to 0.3 dB/km), stimulated Brillouin scattering (SBS), a nonlinear optical effect, will place an upper limit on the optical power that can be transmitted through the link. This optical power limitation gets worse as the length of the fiber is increased. Additionally, chromatic dispersion in the fiber will introduce a bandwidth limitation to the analog signal transmitted along a length of fiber. One method of simultaneously reducing both of these limitations is by concatenating lengths of fibers having different Brillouin resonances [2]-[8]. This report discusses the design considerations for creating a long, high-bandwidth, and high SBS threshold fiber optic link by concatenating lengths of differing fiber types. These considerations are then applied to the construction of a 20.4 km link.

2 DESIGN CONSIDERATIONS

2.1 Chromatic Dispersion

When an analog signal is transmitted along a fiber optic link by modulating the intensity or phase of an optical carrier, chromatic dispersion in the fiber will produce a frequency dependent reduction of the transmitted RF power and nonlinear distortions of the transmitted signal [9]-[16]. Similarly, if the polarization of the optical carrier is modulated, chromatic dispersion will produce a frequency dependent rotation of the orientation of modulation which will be converted by polarizers in the receiver into frequency dependent reduction of the transmitted RF power and nonlinear distortions of the transmitted signal [17]-[18]. For intensity modulation, the frequency dependent RF power reduction of the signal can be calculated from the length and dispersion of the optical fiber using the equation [9]

$$P_{RF} \propto \cos^2 \left(\frac{\pi L D \lambda^2 f_{RF}^2}{c} \right), \quad (1)$$

Where L is the length of the fiber, D is the dispersion per unit length of the fiber, λ is the wavelength of the laser, c is the speed of light, and f_{RF} is the modulation frequency. From equation (1), the 3 dB bandwidth of the fiber optic link can be derived to be

$$\Delta f_{3dB} = \sqrt{\frac{4c}{LD\lambda^2}}. \quad (2)$$

For a link employing Corning's SMF-28, a common single mode fiber type with a chromatic dispersion of approximately 17 ps/nm/km, the dispersion limited 3dB

bandwidth calculated using (2) is 16 GHz for a length of 20 km and 12.7 GHz for a length of 40 km.

One method of reducing this bandwidth limitation is by employing a single sideband modulation format. However, a single sideband modulated signal will still suffer nonlinear distortions due to the chromatic dispersion of the fiber [19]. Therefore, to increase the bandwidth while simultaneously reducing nonlinear distortions, dispersion compensation or dispersion management must be employed. Table 1 lists the specified chromatic dispersions and effective mode areas of some commonly deployed single mode telecommunications fibers. As can be seen from the table, optical fibers with chromatic dispersions ranging from -40 to +20 ps/nm/km are available and can be combined to produce a link with near zero dispersion. In addition, dispersion compensating modules based on a variety of technologies can be purchased and used to compensate the dispersion of the link. It should be noted that although there are fibers available with dispersions that are approximately zero at 1550 nm, such fibers will result in an increase in optical nonlinearities, producing new distortions of the signal. For this reason it is preferable to concatenate links with positive and negative dispersion or to compensate the dispersion of the link by using dispersion compensating modules.

TABLE 1
Specified Chromatic Dispersions and Effective Areas for Common Fiber Types

Fiber	Dispersion at 1550 nm (ps/nm/km)	Effective Area (μm^2)
OFS Ultrawave IDFX	-40	30
Corning Metrocor	-8	58
Corning LEAF	4	72
OFS TrueWave RS	4	55
OFS TrueWave Reach	7	55
Corning SMF-28	17	80
OFS Ultrawave SLA	20	106

2.2 Stimulated Brillouin Scattering

Stimulated Brillouin scattering is a resonant nonlinear optical interaction with the material that results in transmitted light being scattered back towards the input. This process is illustrated in figure 1. In the fiber, thermal fluctuations produce acoustic vibrations (phonons) that travel through the fiber. Most of these phonons exist near the resonant frequency of the material. When light is transmitted through the fiber, photons from the input light scatter off these phonons. This scattering generates a new forward propagating phonon near the resonance frequency and a backward propagating photon (Stokes wave) that is down-shifted by a frequency equal to that of the phonon (figure 1(a)). Since most of the phonons will have a frequency in the narrow band of the resonance frequency of the fiber, if the spectrum of the light is narrow ($< 20\text{-}30$ MHz), the back-scattered Stokes photons will also have a narrow bandwidth centered at the difference between the incident frequency and the resonance frequency. Some of these Stokes photons can also undergo a scattering process in which the Stokes and forward

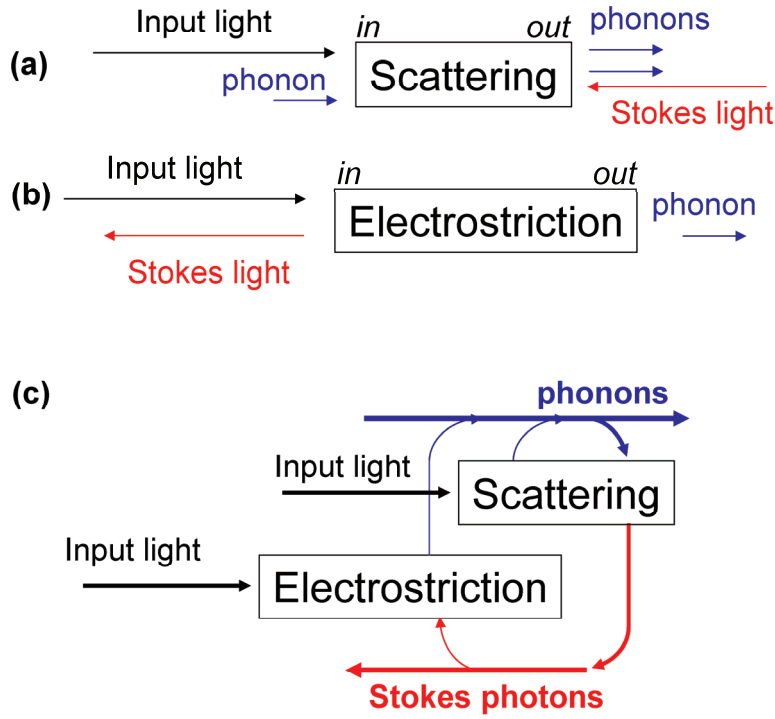


Figure 1. Illustration of Stimulated Brillouin Scattering. (a) input photon scatters off a forward propagating phonon resulting in a down-shifted backwards propagating Stokes photon and an additional phonon. **(b)** The input photon and Stokes photon interact through Electrostriction to generate a forward propagating phonon at the difference frequency. **(c)** Through a cascade of these processes, input light stimulates the scattering of forward propagating light into backwards propagating Stokes light.

propagating photons annihilate (electrostriction), generating more forward propagating phonons at the resonance frequency (figure 1(b)). These, in turn, generate more Stokes photons leading to a cascade of scattering and electrostriction (figure 1(c)). As a result, when the input power is increased this leads to an exponential increase in the amount backscattered light. For system design purposes, it is useful to define a threshold input power at which this effect starts to produce detrimental effects on system performance.

There are several definitions of the Stimulated Brillouin Scattering (SBS) threshold found in the literature [20]-[21]. The most commonly cited formula for the SBS threshold is the one developed in [22]

$$P_{crit} \approx 21 \frac{A_{eff}}{g_B L_{eff}} \quad (3)$$

where A_{eff} is the effective area, α is the loss, $L_{eff} = (1 - \exp(-\alpha L))/\alpha$ is the effective length, and g_B is the Brillouin gain coefficient. The critical power P_{crit} is defined as the input power at which the input pump power is equal to the backscattered Stokes power *assuming no pump depletion*,

$$P_{stokes}(z = 0) = P_{input}(z = 0). \quad (4)$$

This represents the point at which the assumption of pump depletion is invalid. It should be obvious that this condition is physically unrealizable and is therefore not a directly measurable physical quantity.

Based on numerical simulations, Bayvel [23] estimates that for standard fibers, when the input power is equal to P_{crit} , as defined in (3), the Stokes power is equal to approximately 10 % of the input power. Bayvel [23] suggests a more measurable definition of the Stokes threshold as the point at which the backscattered Stokes power is equal to 1% of the input power. The equation for this threshold is

$$P_{th,1\%} \approx 18 \frac{A_{\text{eff}}}{g_B L_{\text{eff}}} . \quad (5)$$

However, although (5) approximately corresponds with the point at which the line width of the Stokes wave reaches it's minimum value [24], neither (3) nor (5) corresponds to an actual physical “threshold” in the commonly used sense of the word. It would be helpful to determine an equation for a more obvious threshold in an optical fiber link. One such threshold is the point where the backscattered stokes wave intensity surpasses the backscattered intensity from Rayleigh scattering, which will be referred to as the SBS noise threshold, P_{nt} .

An approximate estimate for the SBS noise threshold can be determined by following the methodology from [22]. Assuming a linear Rayleigh scattering from the fiber, the threshold condition can be written as

$$P_{s0,\text{eff}} G_{\text{SBS}} = R P_p(0), \quad (6)$$

where $P_{s0,\text{eff}}$ is the effective Stokes power of one photon at a distance of $L_{\text{eff}} = [1 - \exp(-\alpha L)]/\alpha$, G_{SBS} is the SBS gain, R is the Rayleigh reflection coefficient, and $P_p(0)$ is the pump power at the input of the fiber ($z = 0$). From [22],

$$G_{\text{SBS}} = \frac{\exp(g_B L_{\text{eff}} P_p / A_{\text{eff}})}{(g_B L_{\text{eff}} P_p / A_{\text{eff}})} \text{ and} \quad (7)$$

$$P_{s0,\text{eff}} = \frac{\sqrt{\pi}}{2} (kT) \left(\frac{\nu_s}{\nu_a} \right) \left(\frac{\Delta \nu_{\text{fwhm}}}{(g_B L_{\text{eff}} P_p / A_{\text{eff}})^{1/2}} \right)$$

where ν_s is the frequency of the stokes wave, ν_a is the phonon frequency, k is the Boltzman constant, T is the temperature, and $\Delta \nu_{\text{fwhm}}$ is the bandwidth of the gain spectrum. Putting these into (6) results in the expression

$$\left\{ \left[\left(kT \right) \left(\frac{\nu_s}{\nu_a} \right) \frac{\sqrt{\pi}}{2} \Delta \nu_{\text{fwhm}} \right] / \left[\left(\frac{g_B L_{\text{eff}} P_{nt}}{A_{\text{eff}}} \right)^{3/2} \right] \right\} \exp \left(\frac{g_B L_{\text{eff}} P_{nt}}{A_{\text{eff}}} \right) = R P_{nt} \quad (8)$$

Using the same physical parameters as [22], $T = 293$ K, $\nu_s = 283$ THz, $\nu_a = 16.4$ GHz, $L_{eff} = 1/\alpha$, $g_B = 3 \times 10^{-11}$ m/W, $\alpha = 5 \times 10^{-3}$ m⁻¹ (20 dB/km), $\Delta\nu_{fwhm} = 50$ MHz, and $A_{eff} = 10$ μm^2 , this relation becomes

$$\frac{2.1 \times 10^{-13}}{P_{nt}^{3/2}} e^{600 P_{nt}} = R P_{nt} \quad (9)$$

This can be solved graphically to find P_{nt} . For these parameters, $P_{crit} = 35$ mW (calculated by letting $R = 1$) and the values of P_{nt} obtained for several values of R are shown in Table 2.

TABLE 2
SBS noise threshold for several Rayleigh reflection coefficients

P_{nt}	R
26 mW	1×10^{-2}
24 mW	5×10^{-3}
21 mW	1×10^{-3}
20 mW	5×10^{-4}
16 mW	1×10^{-4}
15 mW	5×10^{-5}

From the results shown in Table 2 we can derive the relation:

$$P_{nt} = \left\{ 21 + 2.8 \log(R) \right\} \left(\frac{A_{eff}}{g_B L_{eff}} \right) \quad (10)$$

Note that (10) was derived using values from older fibers at a wavelength of 1.06 μm . If we use values for modern fibers at 1550 nm: $T = 293$ K, $\nu_s = 193$ THz, $\nu_a = 12$ GHz, $L_{eff} = 1/\alpha$, $g_B = 5 \times 10^{-11}$ m/W, $\alpha = 5 \times 10^{-5}$ m⁻¹ (0.2 dB/km), $\Delta\nu_{fwhm} = 20$ MHz, and $A_{eff} = 80$ μm^2 , this relation becomes

$$P_{nt} = \left\{ 19.3 + 3.1 \log(R) \right\} \left(\frac{A_{eff}}{g_B L_{eff}} \right). \quad (11)$$

Note that even this is not a universal relation for all modern fibers. Varying A_{eff} , L_{eff} , or g_B will change the factor $\{19.3 + 3.1 \log(R)\}$ to a new value. For an exact value of the threshold, equation (8) should be used. However, for most modern telecommunication fibers operating at 1550 nm, an approximate value can be obtained using the relation

$$P_{nt} \approx \left\{ 20 + 3 \log(R) \right\} \left(\frac{A_{eff}}{g_B L_{eff}} \right). \quad (12)$$

This equation should give a value that is accurate to within 0.8 dB for current fibers.

3.3 Increasing the SBS Threshold

One method employed to increase the SBS threshold of a fiber optic link is to concatenate several fibers, each having a different phonon resonance frequency [2]-[8]. Because the backward propagating Stokes wave from one fiber does not match the resonant conditions for the previous fiber, electrostriction will not create resonant phonons in that fiber and therefore it will not contribute to SBS in that fiber. As a result, the SBS threshold of each fiber section will depend on the length of only that section, not the length of the fiber link. For a link composed of N sections of fiber having lengths ($L_1, L_2, \dots, L_N$), SBS noise thresholds ($P_{nt,1}, P_{nt,2}, \dots, P_{nt,N}$), and loss coefficients ($\alpha_1, \alpha_2, \dots, \alpha_N$) the SBS threshold limited power *at the input of the link* due to section n , neglecting splice loss, will be

$$P_{link_th}(n) \approx P_{nt,n} \exp\left(\sum_{l=1}^{n-1} \alpha_l L_l\right)$$

or, in dB

$$P_{link_th,dBm}(n) \approx 10 \log(P_{nt,n}) + \sum_{l=1}^{n-1} fiber_loss_l(dB). \quad (13)$$

Ideally, the fibers can be chosen such that $P_{link_th}(1) = P_{link_th}(2) = \dots = P_{link_th}(N)$, resulting in an SBS threshold of $P_{link_th}(1)$ for the total link. However, if P_{link_th} for one section is lower than all of the other sections of the fiber, The SBS threshold for the entire link will be equal to P_{link_th} for this section.

For example, a link employing two fiber types with the same Brillouin gain g and loss α , consisting of a length $L/3$ of one fiber type followed by a length $2L/3$ of the second fiber type will have an SBS limited input power from each section of

$$P_{link_th}(L/3) \approx \{20 + 3 \log(R)\} \frac{\alpha A_{eff}}{g(1 - \exp(-\alpha L/3))} \exp(0)$$

$$P_{link_th}(2L/3) \approx \{20 + 3 \log(R)\} \frac{\alpha A_{eff}}{g(1 - \exp(-2\alpha L/3))} \exp(\alpha L/3) \quad (14)$$

For a 5 km link having $\alpha = 0.25$ in each fiber, $P_{link_th}(2L/3) < P_{link_th}(L/3)$ and therefore the threshold will be equal to $P_{link_th}(2L/3)$. This results in a threshold that is approximately 2.8 dB higher than the threshold for a single fiber with gain g , length 5 km, and loss $\alpha = 0.25$ (assuming similar effective areas for the fibers). Likewise, if the length, L , is 24.9 km, both sections will have the same P_{link_th} and the SBS threshold of the link will be $P_{SBS} = P_{link_th}(2L/3) = P_{link_th}(L/3)$. This results in a threshold 3 dB higher than the threshold for a single fiber with gain g , length 24.9 km, and loss $\alpha = 0.25$ (assuming similar effective areas for the fibers).

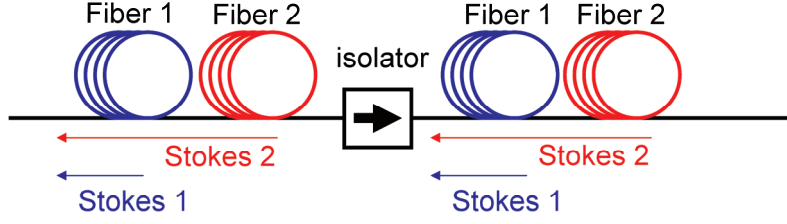


Figure 2. Placing isolators between groups of fibers will prevent the Stokes waves from propagating into prior fibers, allowing fibers with the same Brillouin frequency to be re-used in the same link.

The threshold can be increased further by incorporating isolators into the link as shown in figure 2. The isolators will prevent the backward propagating Stokes waves generated by one set of fibers from propagating into the previous group of fibers. Therefore a link consisting of a repeating pattern of fiber types can be used to create a long link with an increased SBS threshold. In the ideal case, a link can be created to produce the propagation condition illustrated in figure 3. Light launched into the link at the SBS threshold of the first fiber, after attenuation due to fiber loss, enters each following fiber section at the SBS threshold of that fiber section ($P_{\text{link_th}}(1) = P_{\text{link_th}}(2) = \dots = P_{\text{link_th}}(N)$).

From the above discussion it would appear that, in theory, by choosing enough sufficiently short lengths of fiber any SBS threshold can be obtained. In reality, each splice of two fiber types introduces a small loss of 0.01 to 0.1 dB, depending on the similarity of the fiber core sizes. Furthermore, each isolator will add an additional 0.2 to 0.5 dB of loss. As a result, optimizing the Brillouin threshold alone may result in a high loss link. Depending on the power of the available optical sources and the increase in Brillouin threshold, this may result in a link that delivers less optical power to the output than a lower loss, lower threshold link.

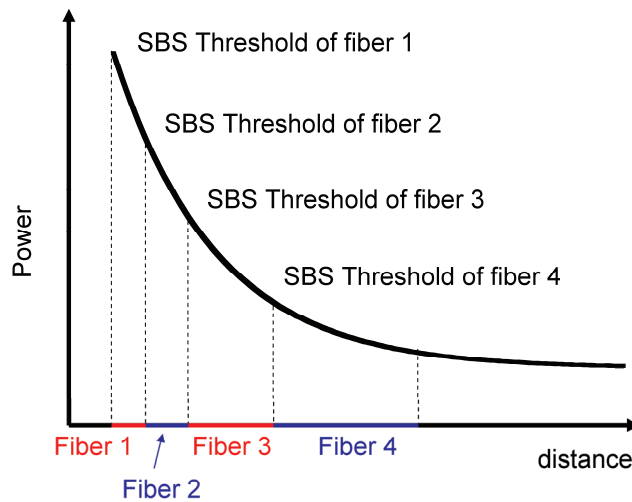


Figure 3. Optical power as a function of distance through an ideal link with an input power equal to the SBS threshold of the first fiber in the link.

3 CONSTRUCTION OF A 20 km LINK

3.1 Characterization of component fibers

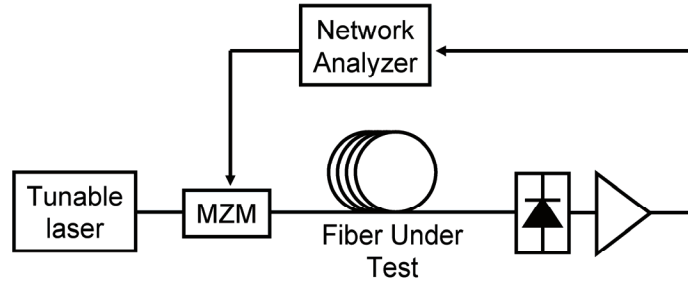


Figure 4. Experimental setup used to measure chromatic dispersion

Four types of fiber were considered for use in construction of the link. To determine which fibers would be used, the chromatic dispersion, Brillouin resonance frequency, and SBS gain of each fiber was measured. The dispersion of each type of fiber was measured with a variation of the modulation phase shift method [25]-[26] using the setup shown in figure 4 [27]. Light from a tunable laser was modulated using an MZM and transmitted through the fiber under test. A network analyzer was used to measure the relative change in delay as a function of wavelength. By measuring the change in delay about a given wavelength, the chromatic dispersion could be determined. Table 3 shows the measured chromatic dispersion at 1550 nm for three of the four fiber types considered for this link.

The SBS threshold was measured using the setup shown in figure 5. Light from a DFB laser was amplified to a power of 100 mW (20 dBm) and attenuated with a variable attenuator. This light was then sent through a 2 x 2 50/50 coupler. The optical power entering the coupler was measured using an in-line power meter (PM 1) and one output of the coupler was transmitted through the fiber under test. At the end of the link, the power was measured using a power meter (PM 2). The second input of the coupler was used to monitor the backscattered light. The SBS gain spectrum was measured by connecting this coupler input to a photodiode and recording the spectrum with an electrical spectrum analyzer (ESA). The recorded spectra of the four tested fibers are shown in figure 6(a). The SBS threshold was measured by replacing the photodiode with a power meter (PM 3). Using the variable attenuator, the power into the link was increased while the power into, out of, and backscattered from the link was measured.

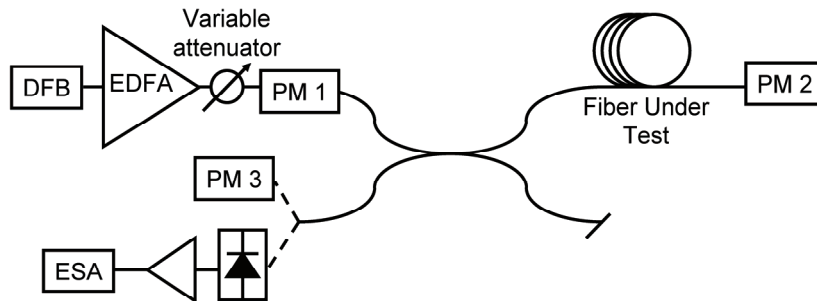


Figure 5. Setup used to measure Brillouin gain spectra and SBS threshold.

Figure 6(b) shows the results of this measurement for a 25 km spool of OFS Truewave Reach singlemode fiber. The SBS threshold corresponds to the input power at which the increase in backscattered light becomes non-linear. The SBS threshold and the ratio (A_{eff}/g_B) calculated from this threshold using (8), for each of the fiber types, are shown in Table 3.

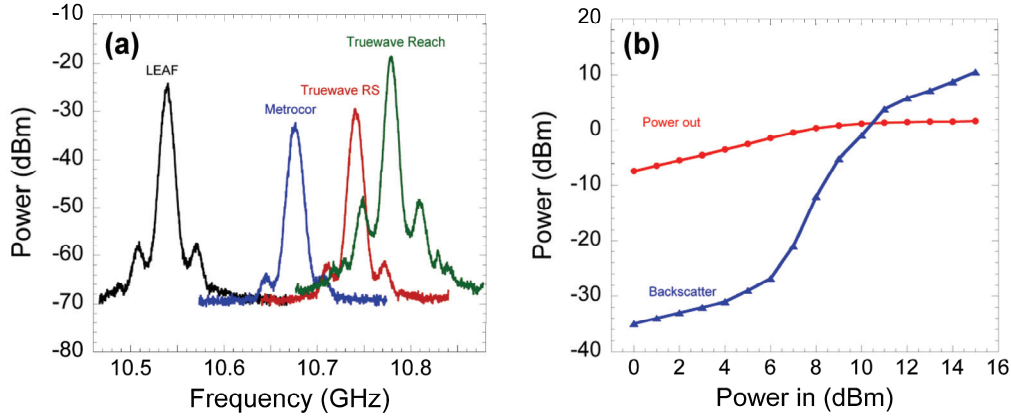


Figure 6. (a) Brillouin gain spectra for available fibers. Note that the ~30 MHz sidebands are due to electrical noise and are not part of the gain spectra. (b) SBS threshold measurement results for a 25 km span of Truewave Reach fiber.

TABLE 3
Measured Chromatic Dispersion and SBS Thresholds for Available Fibers

Fiber Type	Dispersion at 1550 nm (ps/nm/km)	SBS Threshold for 25 km of fiber (dBm)	A_{eff}/g_B (mW*km)
Corning Metrocor	-7.4	6	5.3
Corning LEAF	4.1	8	7.7
OFS Truewave RS	4.2	6	5.3
OFS Truewave Reach	Not measured*	4	3.4

* Due to low SBS threshold, this fiber was removed from consideration for use before dispersion measurements were performed.

3.2 Link design and characterization

A 100 μ s delay line was designed and built using the available fibers. The link was designed to optimize the SBS threshold while maintaining a total chromatic dispersion of between 10 ps/nm and -10 ps/nm for wavelengths near 1550 nm, and limiting the total loss through the link to less than 6 dB. To minimize the number of splices, only two types of fiber were used for most of the link. Assuming a conservative average loss of ~0.25 dB/km for the fiber, the total expected loss from 20.4 km of fiber would be 5.1 dB. Therefore, since each isolator will have a loss of 0.2 - 0.5 dB, only two isolators were used to ensure that the total loss would be less than 6 dB. A schematic of the final link design is shown in figure 7. Three spans consisting of approximately dispersion matched lengths of Corning's Metrocor and LEAF fiber were separated by isolators. A shorter length of a third type of fiber was placed at the start of the link. This allowed the testing of the 19.6 km link to determine the exact length of additional fiber needed, as well as to determine the total dispersion needed to adjust for any non-uniformity in chromatic dispersion for the other two fibers that could produce a higher

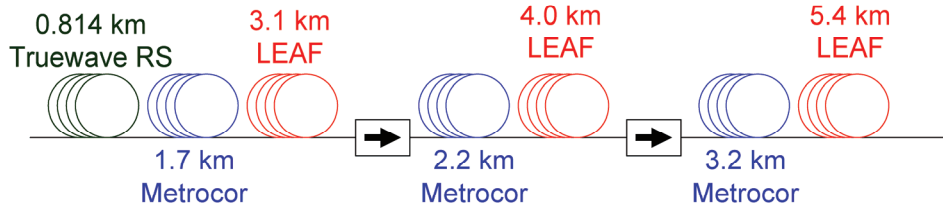


Figure 7. Fiber lengths and arrangement for 20.4 km link

than expected total dispersion. After testing, 0.814 km of Truewave RS fiber was used for this section of the link.

The optical length of the link was measured using the setups shown in figures 8(a) and 8(b). First, a rough estimate of the length was obtained using the setup shown in figure 8(a). An RF signal generator was used to generate pulses of an RF tone that were 1 μ s wide and had a period of 200 μ s. This signal was modulated onto the output of a tunable laser using an MZM. The pulses were transmitted through the link and detected with a photodiode. The output of the photodiode was amplified and detected using an electrical spectrum analyzer (ESA) with a bandwidth of 2 MHz, a span of zero, a sweep time of 200 μ s, and with the sweep triggered by the RF source. By measuring the position of the pulse on the ESA for the setup both with and without the 20.4 km link, the delay of the link could be determined to within approximately 5 μ s. (The resolution was limited by the ESA used in the experiment.) The link was then tested using the setup shown in figure 8(b) to obtain a finer resolution measurement of the length. In this setup, the MZM was driven by port 1 of the network analyzer and the amplified output of the photodiode was sent to port 2. With the 20.4 km span removed from the setup, the S21 signal of the network analyzer was calibrated over the frequency ranges of 0.05-20 GHz and 8-12 GHz. The fiber span was then placed back into the setup and the electrical delay over both frequency ranges was measured. The measured length of the link was 99.95 μ s. Note that although this second method provides a higher resolution measurement it has a limited range (determined by the frequency ranges used and the number of points

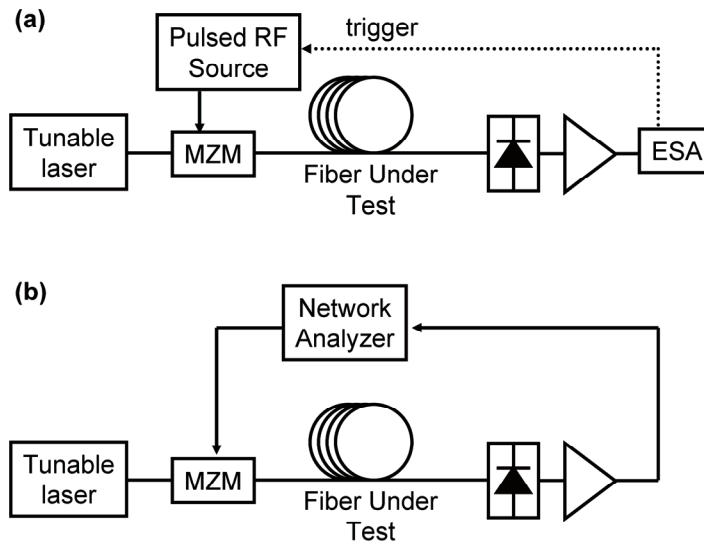


Figure 8. Setups used to measure length of fiber link

TABLE 4
Measured Chromatic Dispersion and SBS Threshold For Link Components

Fiber Section	Chromatic Dispersion (ps/nm)	Measured SBS Threshold (dBm)
1.7 km Metrocor	-13.0	14-15
3.1 km LEAF	13.3	14
2.2 km Metrocor	-16.7	14
4.0 km LEAF	16.5	12
3.2 km Metrocor	-24.3	8-9
5.4 km LEAF	22.7	8
Full Link	1.6	14

collected) and will produce a result equal to the actual length $\pm$ some integer multiple of the technique's measurement range. As a result, if the length is not known to within this measurement range, this technique could give a faulty result. Therefore, the second technique should not be the sole method used to determine the total length of the link.

The dispersion and SBS threshold of each section, and of the final link, was measured using the setups shown in figures 3 and 4. These results are listed in table 4. An expected SBS threshold of the final link can be determined based on the loss through the link and the measured SBS thresholds of the individual sections. This is illustrated in figure 9. From this figure it can be seen that the SBS threshold is limited by the final 5.4 km of LEAF, resulting in a SBS threshold at the input of the span which can be calculated using (13) (modified to include isolator loss) to be

$$P_{link_th,dBm}(5.4 \text{ km LEAF}) = 10 \log(P_{th}(5.4 \text{ km LEAF})) + 15 \text{ km_fiber_loss} + \text{isolator_loss} \quad (15)$$

$$= 12.55 \text{ dBm.}$$

Equation (15) assumes a fiber loss of 0.25 dB/km and an additional loss of 0.4 dB per

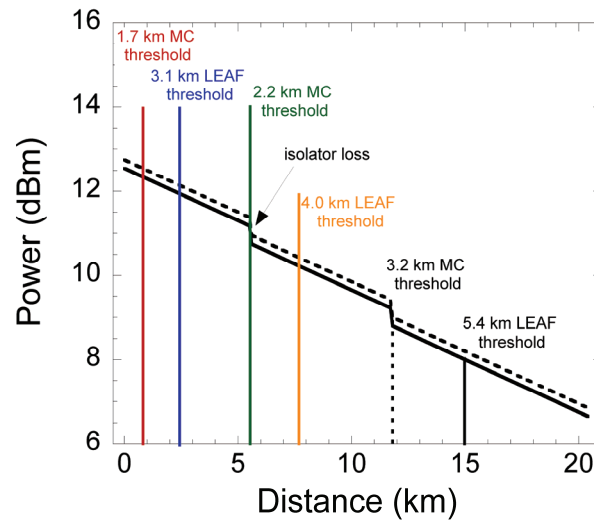


Figure 9. Extrapolated power vs. distance through the link for input optical powers of 12.75 dBm (dashed) and 12.55 dBm (solid).

isolator, and uses the measured SBS threshold of the 5.4 km LEAF section for P_{th} . Note that because of the isolators in the link, if the SBS of the full link is measured using the setup in figure 5, only the backscattered light from the portion of the link prior to the first isolator will be observed. As a result, this measurement will produce a deceptively high value for SBS threshold. This can be seen in the measurement of the full link shown in figure 10. The measured SBS threshold is 14 dBm, which is the same as the threshold for the 3.1 km section of LEAF fiber prior to the first isolator, and higher than the threshold calculated in (15) based on the threshold of the final 5.4 km section of LEAF fiber.

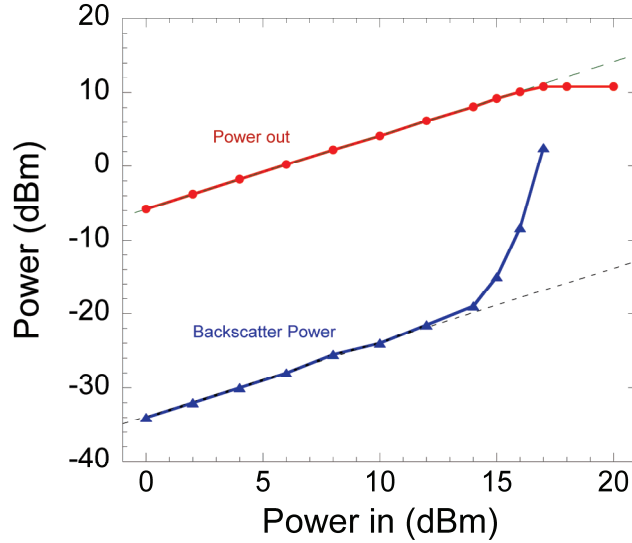


Figure 10. Results of SBS threshold measurement for the full 20.4 km link, performed using the setup shown in figure 5.

CONCLUSIONS

This report has discussed the limitations imposed upon fiber optic links by chromatic dispersion and SBS. A useful definition for a SBS threshold was determined and a formula for estimating this threshold was derived. A technique for reducing the effects of both chromatic dispersion and SBS, concatenating lengths of different fiber types, was described and analyzed. Finally, the practical considerations for creating such a link were discussed and applied to the construction of a 20.4 km link.

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