International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-2 Issue-1, March 2013

Comparison of SRS & SBS (Non Linear Scattering) In Optical Fiber

Rahul Umesh Kale, Pavan Mahadeo Ingale, Rameshwar Tukaram Murade

***Abstract*—The nonlinear scattering effects in optical fiber occur due to thermal molecular vibrations within the fiber. Due to molecular vibration produces the phonon. This phonon also produces due to incident photon. This paper describes basic of SBS (stimulated Brillouin scattering) & SRS (stimulated Raman scattering).Also do the comparative study of their thresholds, reduction in power penalty and applications.**

***Index Terms*—Fiber nonlinearity; Fiber optic communications, stimulated Brillouin scattering, stimulated Raman scattering.**

I. INTRODUCTION

The nonlinearities can be classified into two categories. The first occurs because of scattering effects in the fiber medium due to the interaction of light waves with phonons (molecular vibrations) in the silica medium. The two main effects in this category are stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS). The second set of effects occurs because of the dependence of refractive index on the optical power. In scattering effects, energy gets transferred from one light wave to another wave at a longer wavelength (or lower energy). The lost energy is absorbed by the molecular vibrations, or phonons, in the medium. (The type of phonon involved is different for SBS and SRS.) There are two waves Stokes wave & the Pump wave. As the pump propagates in the fiber, it loses power and the Stokes wave gains power. In the case of SBS, the pump wave is the signal wave, and the Stokes wave is the unwanted wave that is generated due to the scattering process. In the case of SRS, the pump wave is a high-power wave, and the Stokes wave is the signal wave that gets amplified at the expense of the pump wave. The gain coefficient is a measure of the strength of the nonlinear effect.

II. STIMULATED RAMAN S CATTERING

If two or more signals at different wavelengths are injected into a fiber, SRS causes power to be transferred from the lower-wavelength channels to the higher-wavelength channels (see Fig.1). This coupling of energy from a lower-wavelength signal to a higher-wavelength signal is a fundamental effect that is also the basis of optical amplification and lasers.

The energy of a photon at a wavelength k is given by *hc/k*, where h is Planck's constant (6.63 x 10 -34 J s). Thus, a photon of lower wavelength has a higher energy. The transfer of energy from a signal of lower wavelength to a signal of higher wavelength corresponds to emission of photons of lower energy caused by photons of higher energy.

A. Basic Theory

Unlike SBS, SRS is a broadband effect. Figure 1 shows its gain coefficient as a function of wavelength spacing. The peak gain coefficient gR is approximately 6 x 10 $^{-14}$ ~ at 1.55 µm, which is much smaller than the gain coefficient for SBS. However, channels up to 15 THz (125 nm) a part will be coupled with SRS. Also SRS causes coupling in both the direction of propagation and the reverse direction. While SRS between channels in a WDM system is harmful to the system, we can also use SRS to provide the following set of two coupled equations [3]

$$\frac{dI_p}{dz} = -g_R I_p I_s - \alpha_p I_p ----(1)$$

$$\frac{dI_s}{dz} = g_R I_p I_s - \alpha_s I_s ----(2)$$

Where gR is the SRS gain.

In the case of backward SRS, a minus sign is added in front of the derivative in Eq. (2), and this set of equations becomes identical to the SBS case the spectrum of the Raman gain depends on the decay time associated with the excited vibrational state. In the case of a molecular gas or liquid, the decay time is relatively long (1 ns), resulting in a Raman-gain bandwidth of 1 GHz. In the case for optical fibers, the bandwidth exceeds 10 THz. Figure 2 shows the Raman-gain spectrum of silica fibers. The broadband and multipeck nature of the spectrum is due to the amorphous nature of glass. More specifically, vibrational energy levels of silica molecules merge together to form a band. As a result, the Stokes frequency ω s can differ from the pump frequency ω p over a wide range. The maximum gain occurs when the Raman shift $\Omega R \equiv \omega p - \omega s$ is about 13 THz. Another major peak occurs near 15 THz while minor peaks persist for values of ΩR as large as 35 THz. The peak value of the Raman gain gR is about $1\times10-13$ m/W at a wavelength of 1 µm. This value scales linearly with ωp (or inversely with the pump wavelength λ p), resulting in $g_R \approx 6\times10-13$ m/W at 1.55 µm.

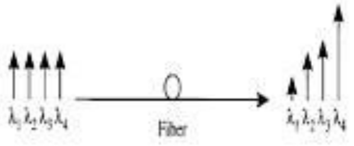

Fig.1. The effect of SRS. Power from lower-wavelength channels is transferred to higher-wavelength channels

Revised Manuscript Received on 30 March 2013.
* Correspondence Author
Mr. Rahul Umesh Kale completed his degree in Electronics & Telecoounication from Shivaji University, Kolhapur. Currently he Pursuing M.Tech (ECE) from Shaaz College of Engineering, JNTU, Hyderabad (A.P).
Mr. Pavan Mahadeo Ingale Completed his degree in Electronics & Telecoounication from Shivaji University, Kolhapur. Currently he Pursuing M.Tech (ECE) from Shaaz College of Engineering, JNTU, Hyderabad (A.P).
Mr. Rameshwar Tukaram Murade Completed his degree in Electronics & Telecoounication from Shivaji University, Kolhapur. Currently he Pursuing M.Tech (ECE) from Shaaz College of Engineering, JNTU, Hyderabad (A.P).

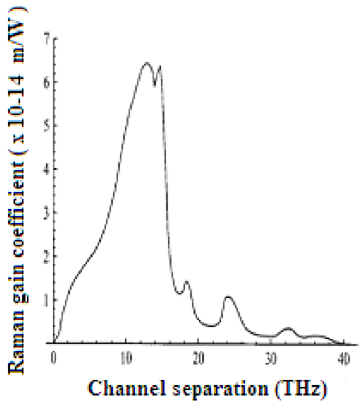

Fig.2. SRS gain coefficient as a function of channel separation

B. *The Raman Process*

In quantum mechanical picture, Raman effect is a process, which involves double quantum molecular transition. In most frequent Stokes scattering process, the energy of incident photon (ħωP) is reduced to lower level (ħωS) and difference energy is transferred to molecule of silica in form of kinetic energy, inducing stretching, bending or rocking of the molecular bonds [1]. The Raman shift ωR (= ωp − ωs) is dictated by the vibrational energy levels of silica. The Stokes Raman process is also known as the forward Raman process and the energy conservation for the process is

$$Eg + \hbar\omega P = Ef + \hbar\omega S$$

Where Eg and Ef are ground state and final state energies respectively. The absorption of incident photon, the emission of scattered photon and transition of the molecule to excited state occurs simultaneously in one step. Therefore, Raman process may be considered as a single step process, which makes stimulated Raman effect possible whenever sufficient numbers of Stokes photons are created. At this juncture it is worth to mention that, in step wise transitions, the absorption and emission of photons occur through two consecutive single quantum transitions via a third molecular energy level. Such transitions are associated with complete disruption of the phase of a molecule after each act of absorption and emission of a single quantum.

C. *Threshold Power*

The incident photon produces a phonon of acoustic frequency & scattered photon. This produces an optical frequency shift varies with scattering angle. The frequency shift in maximum in backward direction & reduces zero in forward direction. The Threshold power is given by,

$$P_r = 5.9 * 10^{-2} d^2 \lambda \alpha db Watt$$

Similar to the case of SBS, the threshold power P_{th} is defined as the incident power at which half of the pump power is transferred to the Stokes field at the output end of a fiber of length L. It is estimated from [3].

$$\frac{g_R P_{th} L_{eff}}{A_{eff}} \approx 16 ----(3)$$

Where g_R is the peak value of the Raman gain. As before, L_{eff} can be approximated by 1/α. If we replace A_{eff} by πw^2, where w is the spot size, P_{th} for SRS is given by,

$$P_{th} \approx \frac{16\alpha(\Pi\omega^2)}{g_R} ----(4)$$

If we use $\pi w^2 = 50\ \mu m^2$ and α = 0.2 dB/km as the representative values, P_{th} is about 570 mW near 1.55 μm. It is important to emphasize that Eq. (4) provides an order of magnitude estimate only as many approximations are made in its derivation. As channel powers in optical communication systems are typically below 10 mW, SRS is not a limiting factor for single-channel light wave systems.

D. *Power Penalty*

The physical layer design must take into account the effect of a number of system impairments as previously discussed. Usually each impairment results in a power penalty to the system. In the presence of impairment, a higher signal power will be required at the receiver in order to maintain a desired bit error rate. One way to define the power penalty is as the increase in signal power required (in dB) to maintain the same bit error rate in the presence of impairments. Presence of dispersion reduces the SRS penalty. In presence of dispersion, signals in different channels travel at different velocities and hence reducing chances of overlap between pulses propagating at different wavelengths. By decreasing channel spacing SRS penalty can be reduced.

The power level should be kept below threshold level which requires the reduction in distance between amplifiers The SRS imposed limitations on the maximum transmit power per Channel.

E. *Applications of SRS (Raman Amplifiers)*

We studied stimulated Raman scattering (SRS) as one of the nonlinear impairments that affect signals propagating through optical fiber. The same nonlinearity can be exploited to provide amplification as well. Therefore, by pumping a fiber using a high-power pump laser, we can provide gain to other signals, with a peak gain obtained 13 THz below the pump frequency. For instance, using pumps around 1460-1480 nm provides Raman gain in the 1550-1600 nm window. A few key attributes distinguish Raman amplifiers from EDFAs. Unlike EDFAs, we can use the Raman effect to provide gain at any wavelength. An EDFA provides gain in the C- and L-bands (1528-1605 nm). Thus Raman amplification can potentially open up other bands for WDM, such as the 1310 nm window, or the so-called S-band lying just below 1528 nm. Also, we can use multiple pumps at different wavelengths and different powers simultaneously to tailor the overall Raman gain shape.

Second, Raman amplification relies on simply pumping the same silica fiber used for transmitting the data signals, so it can be used to produce a lumped or discrete amplifier, as well as a distributed amplifier. In the lumped case, the Raman amplifier consists of a sufficiently long spool of fiber along with the appropriate pump lasers in a package. In the distributed case, the fiber can simply be the fiber span of interest, with the pump attached to one end of the span, as shown in Figure 3 Today the most popular use of Raman amplifiers is to complement EDF As by providing additional gain in a distributed manner in ultra-long-haul systems. The biggest challenge in realizing Raman amplifiers lies in the pump source itself. These amplifiers require high-power pump sources of the order of 1 W or more, at the right wavelength. The noise sources in Raman amplifiers are somewhat different from EDFAs. The Raman gain responds instantaneously to the pump power. Therefore fluctuations in pump power will cause the gain to vary and will appear as crosstalk to the desired signals. This is not the case with EDFAs.

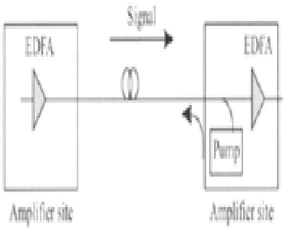

Fig.3. Distributed Raman amplifier using a backward propagating pump, shown operating along with discrete erbium-doped fiber amplifiers.

Therefore, for Raman amplifiers, it is important to keep the pump at a constant power. Having the pump propagate in the opposite direction to the signal helps dramatically because fluctuations in pump power are then averaged over the propagation time over the fiber. To understand this, first consider the case where the pump propagates along with the signal in the same direction. The two waves travel at approximately the same velocity. In this case, when the pump power is high at the input, the signal sees high gain, and when the power is low, the signal sees a lower gain. Now consider the case when the signal and pump travel in opposite directions. To keep things simple, suppose that the pump power varies between two states: high and low. As the signal propagates through the fiber, whenever it overlaps with the pump signal in the high power state, it sees a high gain. When it overlaps with the pump signal in the low power state, it sees a lower gain. If the pump fluctuations are relatively fast compared to the propagation time of the signal across the fiber, the amplification within optical fibers. The SRS process in fiber causes energy transfer from the pump to the signal [2].

III. STIMULATED BRILLOUIN SCATTERING (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. For an oscillating electric field at the pump frequency $\Omega\ p$, this process generates an acoustic wave at some frequency Ω. Spontaneous 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 Ωs. The scattering process must conserve both the energy and the momentum. The energy conservation requires that the Stokes shift Ω equals $\omega p - \omega s$. The momentum conservation requires that the wave vectors satisfy $k_A = k_p - k_s$. Using the dispersion relation $|k_A| = \Omega / v_A$, where v_A is the acoustic velocity, this condition determines the acoustic frequency as,

$\Omega = |k_A| v_A = 2 v_A |k_p| \sin(\theta/2)$ …………….. (5)

Where $|kp| \approx |ks|$ was used and θ represents the angle between the pump and scattered waves. Note that Ω vanishes in the forward direction ($\theta = 0$) and is maximum in the backward direction ($\theta = \pi$).

The feedback process is governed by the following set of two coupled equations [3].

$$\frac{dI_p}{dz} = -g_B I_p I_s - \alpha_p I_p \text{ ----(6)}$$

$$\frac{-dI_s}{dz} = g_B I_p I_s - \alpha_s I_p \text{ ----(7)}$$

Where I_p and I_s are the intensities of the pump and Stokes fields, g_B is the SBS gain, and α_p and α_s account for fiber losses. The SBS gain g_B is frequency dependent because of a finite damping time T_B of acoustic waves (the lifetime of acoustic phonons). If the acoustic waves decay as exp $(-t/T_B)$, the Brillouin gain has a Lorentzian spectral profile given by

$g_B(\Omega) = g_B(\Omega_B) / 1 + (\Omega - \Omega_B)^2 T^2_B$ ………………….. (8)

Figure 4 shows the Brillouin gain spectra at $\lambda\, p = 1.525\ \mu m$ for three different kinds of single-mode silica fibers. Both the Brillouin shift ν_B and the gain bandwidth $\Delta\nu_B$ can vary from fiber to fiber because of the guided nature of light and the presence of dopants in the fiber core.

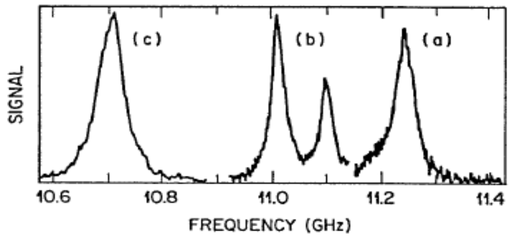

Fig.4. Brillouin-gain spectrum measured using a 1.525µm pumps for 3 fibers with different Germania doping: (a) Silica-core fiber (b) depressed-cladding fiber (c) dispersion-shifted fiber. Vertical scale is arbitrary.

In Fig. 4 has a core of nearly pure silica (Germania concentration of about 0.3% per mole). The measured Brillouin shift $\nu_B = 11.25$ GHz is in agreement with Eq. (5). The Brillouin shift is reduced for fibers (b) and (c) of a higher Germania concentration in the fiber core. The doublepeak structure for fiber (b) results from inhomogeneous distribution of Germania within the core. The gain bandwidth in Fig. 4 is larger than that expected for bulk silica ($\Delta\nu_B \approx 17$ MHz at $\lambda_p = 1.525\ \mu m$). A part of the increase is due to the guided nature of acoustic modes in optical fibers. However, most of the increase in bandwidth can be attributed to variations in the core diameter along the fiber length. Because such variations are specific to each fiber, the SBS gain bandwidth is generally different for different fibers and can exceed 100 MHz; typical values are 50 MHz for λ_p near 1.55µm.

A. *Threshold Power*

The equation for optical power threshold for long single mode fiber is given by,

$P_B = 4.4 \times 10^{-3} d^2 \lambda^2 \alpha$ db v Watts

The calculation of the threshold power for SBS P_{th} is quite involved, and we simply state the following approximation for it from [1]

$P_{th} = 21 b A_{eff} / g_B L_{eff}$ ………………….. (9)

Here, A_{eff} and L_{eff} are the effective area and length of the fiber, respectively $g_B \sim 4 \times 10^{-11}$ m/W is called the Brillouin gain coefficient, and the value of b lies between 1 and 2 depending on the relative polarizations of the pump and Stokes waves. Assuming the worst-case value of b = 1,

$A_{eff} \approx 50 \mu m2$, and $L_{eff} \approx 20$ km, we get $P_{th} = 1.3$ mW. Since this is a low value, some care must be taken in the design of optical communication systems to reduce the SBS penalty. The preceding expression assumes that the pump signal has a very narrow spectral width and lies within the narrow 20 MHz gain bandwidth of SBS.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The threshold power is considerably increased if the signal has a broad spectral width, and thus much of the pump power lies outside the 20 MHz gain bandwidth of SBS.

The SBS penalty can be reduced in several ways,

1. Keep the power per channel to much below the SBS threshold. The trade-off is that in a long-haul system, we may have to reduce the amplifier spacing.

2. Since the gain bandwidth of SBS is very small, its effect can be decreased by increasing the spectral width of the source. This can be done by directly modulating the laser, which causes the spectral width to increase because of chirp. This may cause a significant chromatic dispersion penalty. The chromatic dispersion penalty can, however, be reduced by suitable chromatic dispersion management, as we will see later. Another approach is to dither the laser slightly in frequency, say, at 200 MHz, which does not cause as high a penalty because of chromatic dispersion but increases the SBS threshold power by an order of magnitude, as we saw earlier. This approach is commonly employed in high-bit-rate systems transmitting at high powers. Irrespective of the bit rate, the use of an external modulator along with a narrow spectral width source increases the SBS threshold by only a small factor for amplitude-modulated systems. This is because a good fraction of the power is still contained in the optical carrier for such systems.

3. Use phase modulation schemes rather than amplitude modulation schemes. This reduces the power present in the optical carrier, thus reducing the SBS penalty.

In this case, the spectral width of the source can be taken to be proportion the bit rate. However, this may not be a practical option in most systems.

B. Reduction in Power Penalty

When any nonlinear effect contributes to signal impairment, an additional amount of power is needed at the receiver to maintain the same BER as in absence of nonlinear effects.

There are many ways to reduce the power penalty due to SBS.

1. Keep the power level per WDM channel much below the SBS threshold. In long-haul systems one may have to reduce the amplifier spacing.
2. The effect of small gain bandwidth of SBS phenomenon can be decreased by increasing the line width of the source used. The line width can be increased because of chirping effect by direct modulation of source laser. This may results in significant dispersion penalty, which can be reduced by suitable dispersion management.
3. Phase modulation methods in place of amplitude modulation methods reduce the power present in optical fiber, which in turn reduces the SBS penalty.

C. Applications of SBS Phenomenon

Normally SBS puts limitations on optical communication systems, but with suitable system arrangement it can be useful for making many optical devices. These are described below [1].

Fiber Sensors:-

The fiber sensors are capable of sensing the temperature and strain over long distances whenever there is change in temperature or strain, the refractive index of silica changes in response to such variations. This change produces change in Brillouin shift. By registering the change in Brillouin shift the distribution of temperature and strain over long distances can be obtained. Sometimes such sensors are also known as distributed fiber sensors. Several methods have been introduced to improve sensing performance in four key areas: spatial resolution, measurement accuracy, total sensing length and measurement-acquisition time. These factors are generally interrelated and improvement in one factor may results in degradation in one or more of the others. Dark pulse Brillouin optical time domain analysis (BOTDA) technique provides improved resolution, accuracy and acquisition time over conventional BOTDA systems without the severe limitations on sensing length often imposed by other high-resolution techniques.

IV. COMPARISON OF RAMAN AND BRILLOUIN PROCESSES

In spite of many similarities between SBS and SRS, the SBS differs from SRS in several ways

1. The Brillouin scattering occurs due to phonon of acoustic frequency & a scattered photon. The Raman scattering is due to molecular vibrations.
2. In SBS frequency shift maximum in backward direction & reduces zero in forward direction. In SRS frequency shift maximum.
3. SRS optical power threshold up to three orders of magnitude higher than SBS.
4. The scattered light is shifted in frequency by about 10 GHz for SBS but by 13 THz for SRS.
5. The Brillouin gain bandwidth is extremely narrow in comparison of Raman gain bandwidth.

V. CONCLUSION

We above discuss two nonlinear scattering phenomenons in fibers and both (SRS & SBS) are related to vibrational excitation modes of silica. But with suitable system arrangement they can be used in many applications. Threshold power for SBS is about 1.289 mW while for SRS, it is about 572mW. The typical value of channel power in optical systems is below 10mW. The scattered light is shifted frequency in SBS is 10GHz & in SRS 13 THz.

REFERENCES

1. Nonlinear scattering effects in optical Fibers S. P. Singh, R. Gangwar, and N. Singh Department of Electronics and Communication University of Allahabad Allahabad-211002, India.
2. Optical networks: A practical Perspective - Rajiv Ram swami & Kumar S. Sivrajan.2 Ed. 2004.
3. Fiber optic communication Third Edition by Govind P. Agarwal.
4. Optical fiber communication – Gerd Keiser, 3rd ed. 2000.
5. Optical fiber communication – Principles & practice John M.Senior, 2 ed. 2000 PE.
6. Boyd, R. W., Nonlinear Optics, Academic Press, SanDiego, CA, 1992.
7. Shen, Y. R. and N. Bloembergen, "Theory of stimulated brillouin and raman scattering," Phys. Rev. A, Vol. 137, 1787–1805, 1965.
8. Nikles, M., L. Thevenaz, and P. A. Robert, "Brillouin gain spectrum characterization in single-mode optical fiber," J. Lightwave. Tech., Vol. 15, 1842–1851, 1997.
9. Cotter, D., "Observation of stimulated Brillouin scattering in lowloss silica fiber at 1.3 μm," Electron. Lett. Vol. 18, 495–496, 1982.
10. Tkach, R. W., A. R. Chraplyvy, and R. M. Derosier, "Spontaneous Brillouin scattering for single-mode optical fiber characterization,"Electron. Lett. Vol. 22, 1011–1013, 1986.

11. Smith, R. G., “Optical power handling capacity of low optical fibers as determined by stimulated Raman and Brillouin scattering,” Appl. Opt., Vol. 11, 2489–2494, 1972.
12. Stolen, R. J., “Polarization effects in Raman and Brillouin lasers,” IEEE J. Quantum Electron., Vol. QE-15, 1157–1160, 1979.
13. Forghieri, F., R. W. Tkach, and A. R. Chraplyvy, “Fiber nonlinerities and their impact on transmission systems,” Optical Fiber Telecommunications-III, I. P. Kaminow and T. L. Koch (eds.), Vol. A, Academic Press, New York, 1997.
14. Kotate, K. and M. Tanaka, “Distributed fiber Brillouin strain sensing with 1-cm spatial resolution by correlation-based continuous-wave technique,” IEEE Photon. Tech. Lett., Vol. 14, 179–181, 2002.
15. Lan, G.-L., P. K. Banerjee, and S. S. Mitra, “Raman scattering in optical fibers,” J. of Raman Spectrosc., Vol. 11, 416–423, 1981.
16. Ohmori, Y., Y. Sasaki, and T. Edahiro, “Fiber-length dependence of critical power for stimulated Raman scattering,” Electron. Lett, Vol. 17, No. 17, 593–594, 1981.
17. Aoki, Y., “Properties of Raman amplifier and their applicability to digital optical communication systems,” J. Lightwave. Tech., Vol. LT-6, 1225–1239, 1988.
18. Anupam, R., M. Chandran, C. K. Anandan, P. Mohanan, and K. Vasudevan, “Scattering behavior of fractal based metallodielectric structures,” Progress In Electromagnetics Research, PIER 69, 323–339, 2007.

AUTHOR PROFILE

Mr. Rahul Umesh Kale completed his degree in Electronics & Telecoounication from Shivaji University, Kolhapur. Currently he Pursuing M.Tech (ECE) from Shaaz College of Engineering, JNTU, Hyderabad (A.P). His active research includes RADAR technology and Optical Communication system.

Mr. Pavan Mahadeo Ingale Completed his degree in Electronics & Telecoounication from Shivaji University, Kolhapur. Currently he Pursuing M.Tech (ECE) from Shaaz College of Engineering, JNTU, Hyderabad (A.P). His research work on the Image Processing and wireless communication system.

Mr. Rameshwar Tukaram Murade Completed his degree in Electronics & Telecoounication from Shivaji University, Kolhapur. Currently he Pursuing M.Tech (ECE) from Shaaz College of Engineering, JNTU, Hyderabad (A.P). His research interests are Soft computing, Mobile Communication system, Wireless Communication system, and Communication protocol.