PHASE TO AMPLITUDE MODULATION CONVERSION USING BRILLOUIN SELECTIVE SIDEBAND AMPLIFICATION

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ABSTRACT

We demonstrate an efficient method for converting a phase modulated signal to an amplitude modulated signal by employing the powerful Brillouin selective sideband amplification technique. We further demonstrate several applications of this technique in various photonic systems, including microwave frequency multiplication, photonic microwave signal mixing with gain, microwave harmonic signal up conversion, and coherent heterodyne signal detection.

INTRODUCTION

Efficient and stable conversion of phase modulation (PM) to amplitude modulation (AM) is extremely important for a system employing phase modulation scheme. Almost all the phase to amplitude modulation conversion is accomplished by either the homodyne method in which a phase modulated optical carrier is made to beat with an unmodulated optical carrier of the same frequency, or the heterodyne method in which the phase modulated optical signal is made to beat with another optical carrier of a different frequency. A good example of the homodyne method is the Mach-Zehnder modulator in which an optical carrier is first split into two beams. One beam is then phase modulated and combines in the photodetector with the other beam to produce a corresponding amplitude modulation.

One major problem associated with the homodyne and heterodyne is the stability, especially when the two beating optical signals are from different sources. Even the commonly used Mach-Zehnder modulator still has drift problems caused by differential path length fluctuations of the two optical arms. Another problem is the optical insertion loss. In order for the modulator to function properly, the modulator must be biased at 50% of the transmission peak, which introduces a 3 dB optical loss. Additional loss may also result from the more completed device structure (e.g. the light beam has to first be split and then recombined).

In this paper we introduce and demonstrate the novel concept of using Brillouin selective sideband amplification (BSSA)[1,2] to achieve efficient PM to AM conversion. The converted amplitude modulation is extremely stable, immune to the fluctuations in the frequency of the optical carrier, the temperature, and the fiber length. In addition, the conversion is much more efficient than any other method because only the desired sideband is amplified. Finally, this approach also provides many important new functions for lightwave communication systems.

THE CONCEPT OF BRILLOUIN I'M TO AM CONVERSION

Fig. la is the experimental setup for demonstrating the concept of Brillouin PM to AM conversion. As shown in the figure, the optical carrier from the signal laser is first phase modulated by a microwave signal and then is transmitted through a 12.8 km fiber to the receiving end. The phase modulation of the optical carrier introduces many sidebands,[3] each having a certain phase and amplitude relationship with the carrier and with each other, as shown in Fig. lb. Although in the optical receiver these sidebands beat with the carrier and beat with each other, they produce no amplitude modulations, because for each beat signal there always exists another beat signal which has the same amplitude and frequency but opposite phase. They cancel each other out perfectly.

Amplitude modulation will result if this perfect balance is broken, and this can be accomplished by using the Brillouin selective sideband amplification technique (BSSA). As shown in Fig. la, a pump beam is injected into the optical fiber from the opposite end of the signal laser and induces, via the eletrorestrictive effect, an acoustic grating moving in the direction of the pump beam along the fiber. Part of the pump beam is then scattered backwards by this moving grating and produces a frequency down-shifted (due to the Doppler effect) light beam propagating in the direction of the signal laser, as shown in Fig. lc. This process is called Brillouin scattering.[4] By tuning the frequency of either the pump laser, the signal laser, or both, the frequency of the backscattered light can be made to coincide with one of the phase modulation sidebands of the signal laser. The interaction of this sideband, the grating, and the pump will further enhance the induced acoustic grating, causing more backscattering of the pump and greatly amplifying the sideband. The amplification of this modulation sideband will break the perfect amplitude balance of sidebands of a phase modulation and cause the phase modulation to convert to an amplitude modulation.

In a demonstration, a microwave signal was used to drive a phase modulator and the output from a photodetector was connected to an RF spectrum analyzer. Without the Brillouin pump, no RF signal was observed. When the pump was turned on and its frequency was aligned with the -1 order sidebands, a strong signal similar to that of Fig. 2a was detected by the spectrum analyzer, indicating an efficient phase modulation to amplitude modulation conversion.

It is interesting to notice that because of its extremely narrow gain bandwidth, Brillouin amplification in digital photonic systems has proved to be impractical.[5,6] However, because of the extremely narrow bandwidth, selective amplification of a particular sideband and the resulting I'M to AM modulation conversion are possible.

APPLICATIONS

1. Frequency *Multiplication*

The Brillouin PM to AM conversion can be used to achieve photonic frequency multiplication using a phase modulator. As shown in Fig. lb and Fig. lc, one may selectively amplify a higher order sideband and obtain beat frequencies which are multiples of the frequency of the RF driving signal. Fig. 2a and Fig. 2b show the received RF spectrum when the -1 order sideband and -5 order sideband were amplified respectively. It is evident from Fig. 2b that frequency components as large as 9 times the frequency of the driving signal were efficiently generated. Note that the phase modulator used has a specified bandwidth of only 0.5 GHz. However, with the aid of the selective Brillouin amplification, it generated frequencies as high as 7 GHz. In the same way, we expect that a common 10 GHz modulator can be used to obtain signals exceeding 100 GHz, especially when it is combined with the harmonic carrier generation technique of C. Sun et al.[7] This efficient Brillouin frequency multiplication is therefore very useful for generating millimeter wave signals without the need for using expensive high speed modulators, high frequency sources, and over driving the modulator.

2. *Signal mixing and harmonic Signal Up Conversion*

In a separate paper,[1] we reported using the concept of BSSA to achieving efficient signal up and down conversion with gain using two amplitude modulators. With the technique of Brillouin PM to AM conversion described above, the signal mixing can even be achieved with two phase modulators, as shown in Fig. 3a and Fig. 3b. If the local oscillator (LO) lower sideband is amplified by BSSA, the beat between the amplified LO sideband and the signal's lower sideband produces an amplified down converted signal. Similarly, the amplified LO lower sideband beating with the signal's upper sideband produces an up-converted signal.

The same concept can be extended to achieve harmonic signal up-conversion if a higher order LO sideband is amplified, as shown in Fig. 3c and Fig. 3d in which the -2 LO sideband is amplified. The amplified LO sideband beating with the upper and lower signal sidebands up-converts the signal to the harmonic of the LO frequency. We demonstrated this frequency multiplied signal up conversion with two low frequency phase modulators (0.5 GHz bandwidth) and the results are shown in Fig. 3e. With the amplification of the -5 order sideband of the 0.8 GHz LO modulation, the 0.1 GHz signal is up converted to 6.4 GHz, a 64 times signal up-conversion. We again expect that with a 10 GHz modulator and 10 GHz LO source, one can easily up-convert a low frequency signal to 100 GHz and beyond, especially when this technique is combined with that demonstrated by C. Sun et al.[7]

One may notice that in Fig. 3e that the harmonics of the signal are also up-converted (the peaks u and v corresponds to the harmonics of the signal, while peaks x and y corresponds to the signal itself). The reason for the signal and its harmonics to be up-converted around each peak in Fig. 3e is because each LO sideband is also modulated by the second phase modulator in Fig. 3a. If the arrangement of Fig. 3b is used, the up-converted signal and its harmonics will only be around peak 5, assuming -5 LO order is amplified.

3. *Phase and Frequency Locking in Coherent Heterodyne Systems*

In a coherent homodyne or heterodyne communication ink,[8] a strong loca oscillator is generally placed in front of the receiver to in erfere with a phas modulated optical signal. The interference converts the phase modulation into an amplitude modulated signal, as shown in Fig. 4. Since the local oscillator is much stronger than the original optical carrier of the signal, the receiving sensitivity will be greatly improved. In order for the system to work properly, typically the signal and the LO laser must be phase locked.

Looking from a different viewpoint, the photonic mixing configuration of Fig. 3a is essentially a coherent heterodyne system with the advantage that the LO laser is automatically phase locked to the signal laser. Instead of directly sending the LO laser signal into the phtodetector\like in a common heterodyne system, here the LO laser (the pump laser in Fig. 3a and Fig. 3b) is sent towards the signal laser. Tuning the frequency of the LO laser to one of the LO modulation sidebands, the sideband will be greatly amplified by the LO laser via the Brillouin amplification process. The amplified LO modulation sideband then goes into the detector and beats with the signal sidebands. The phase and frequency of the amplified LO sideband are derived from the signal laser and therefore are automatically locked to the signal laser, with a stability determined by the electrical LO driving signal. On the other hand, most of the power of the amplified sideband comes from the LO laser. Therefore, the LO laser is indirectly phase locked to the signal laser through the seeded Brillouin amplification process. Such a phase locking scheme is much easier to implement than other laser phase locking schemes.

SUMMARY

We have demonstrated the conversion of phase modulation to amplitude modulation using Brillouin selective sideband amplification (BSSA) so that one can use lower loss and less expensive phase modulators to replace conventional Mach-Zehnder modulators in many photonic systems. Such a replacement not only results in much higher link gain, but also eliminates the bias drift associated with biasing the Mach-Zehnder modulators. In addition, We showed that the BSSA technique can also turn a phase modulator into an efficient photonic frequency multiplier with large multiplication factors, without having to over drive the modulator nor to use high power lasers. Furthermore, we demonstrated using two optical phase modulators to achieve signal down/up conversion with gain. Finally, we showed that this signal down/up conversion scheme provides a novel and simple solution for the difficult laser frequency and phase locking problem in coherent optical communication systems.

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REFERENCES

1. X. S. Yao, "Brillouin selective sideband amplification of microwave photonic signals," submitted to Photonic Technology Letters.

2. X. S. Yao and L. Maleki, "Brillouin amplification--a powerful new scheme for microwave photonic communications," in the Seventh Annual DARPA Symposium on Photonic Systems for Antenna Applications, January 14-16, 1997, Montery, CA.

3. A. Yariv and P. Yeh, *Optical Waves in Crystals*, (John Wiley & Sons, New York, 1984), Chap. 7.

4. G. P. Agrawal, *Nonlinear Fiber Optics*, (Academic Press, Boston, 1989), Chap. 9.

5. N. A. Olsson and J. P. Van Der Ziel, "Characteristics of a semiconductor laser pumped Brillouin amplifier with electronically controlled bandwidth," J. of Lightwave Technology, Vol. LT-5, No. 1, pp. 147-153.

6. C. L. Tang, "Saturation and spectral characteristics of the stokes emission in the stimulated Brillouin process," J. Appl. Phys., vol. 37, pp. 2945-2955 (1966).

7. C. K. Sun, R. J. Orazi, and S. A. Papert, "Efficient Microwave Frequency Conversion Using I'hotonic Link Signal Mixing," IEEE Photonics 'technology Letters, Vol. 8, No. 1, pp. 154-156 (1996), and C. K. Sun, R. J. Orazi, S. A. Papert, and W. Burns, "A Photonic-Link Millimeter-Wave Mixer Using Cascaded Optical Modulators and Harmonic Carrier Generation," IEEE Photonics Technology Letters, Vol. 8, No. 9, pp. 1166-1168 (1996).

8. S. Shimada ed, *Coherent Lightwave Communications Technology*, (Chapman & Hall, London, 1995), Chap. 2.

FIGURE CAPTION

Fig. 1 a) Experimental setup for demonstrating Brillouin phase to amplitude modulation. Both lasers are diode pumped YAG operating at 1320 nrn. b) A spectral diagram illustrating the phase and amplitude relationships between the optical carrier and the modulation sidebands of a phase modulated signal. c) A spectral diagram showing the relationship between the frequencies of the pump laser and the Brillouin backscattered light. In our experiment, the Stocks frequency shift ν_B is 12.8 GHz (not related to the 12.8 km fiber).

Fig. 2 a) The received RF spectrum of a phase modulated signal when the -1 sideband is amplified by Brillouin amplification. The RF input to the modulator has a frequency of 0.8 GHz and a power of 10.83 dBm. The lst, 2nd, 3rd, and 4th peaks are mainly from the amplified -1 sideband beating with the carrier, the +1, +2, and +3 order sidebands respectively. b) The received RF spectrum of the same phase modulated signal when -5 sideband is amplified. The RF input to the modulator has a frequency of 0.8 GHz and a power of 20 dBm. The peaks labeled 1-9 are the results of the amplified -5 RF sideband beating with -4, -3, -2, -1, carrier, +1, +2, +3, and +4 order RF sidebands respectively. An RF filter can be used to select any one of the beating signals. The spectral resolution of the measurements in a) and b) are 100 kHz and 30 kHz respectively.

Fig. 3 a) An arrangement for photonic signal mixing and harmonic signal up-conversion with two cascaded phase modulators. b) An alternative arrangement with two paralleled phase modulators. In the drawing, PBS stands for polarization beamsplitter. c) Spectrum diagram illustrating various LO and signal sidebands. d) Spectrum of Brillouin scattering. e) Experimental result showing the effectiveness of the harmonic signal up-conversion with the arrangement of a). The LO driving the first modulator has a frequency of 0.8 GHz and a power of 21 dBm while the signal driving the second modulator has a frequency of 0.1 GHz and a power of -1.83 dBm. The received optical power at the photodetector is 1.72 mw with the amplification and 0.55 mW without the amplification. As indicated in c), the signal is up-converted to as high as 6.4 GHz with an LO of only 0.8 GHz. The peaks labeled 1 to 8 are the results of the amplified -5 order LO sideband beating with -4,-3,-2,-1, carrier, +1, +2, and +3 order LO sidebands respectively.

Fig. 4. A typical coherent heterodyne communication link. The LO laser must be phase locked to the signal laser.

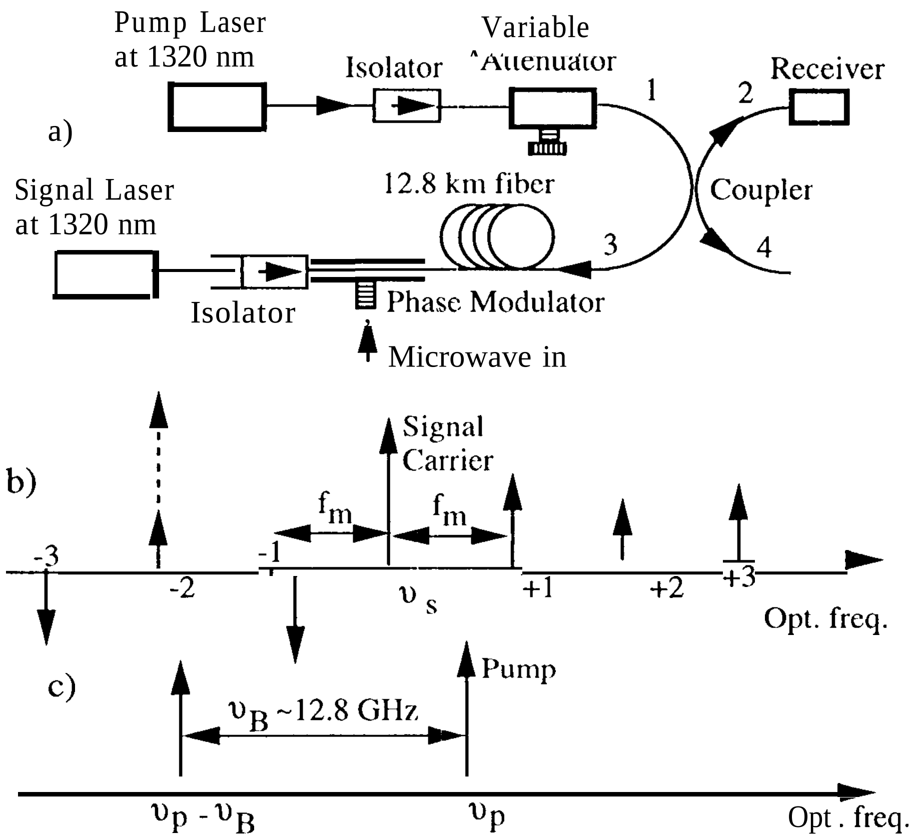

Fig. 1

Yao, "Phase to amplitude modulation conversion using Brillouin selective sideband amplification"

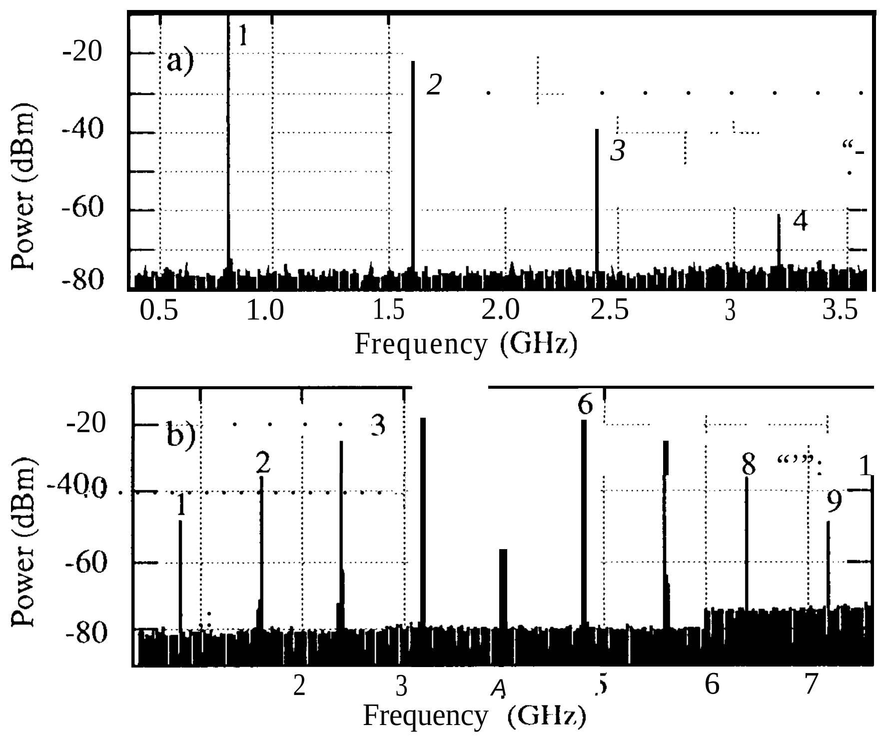

Fig. 2

Yao, “Phase to amplitude modulation conversion using Brillouin selective sideband amplification”

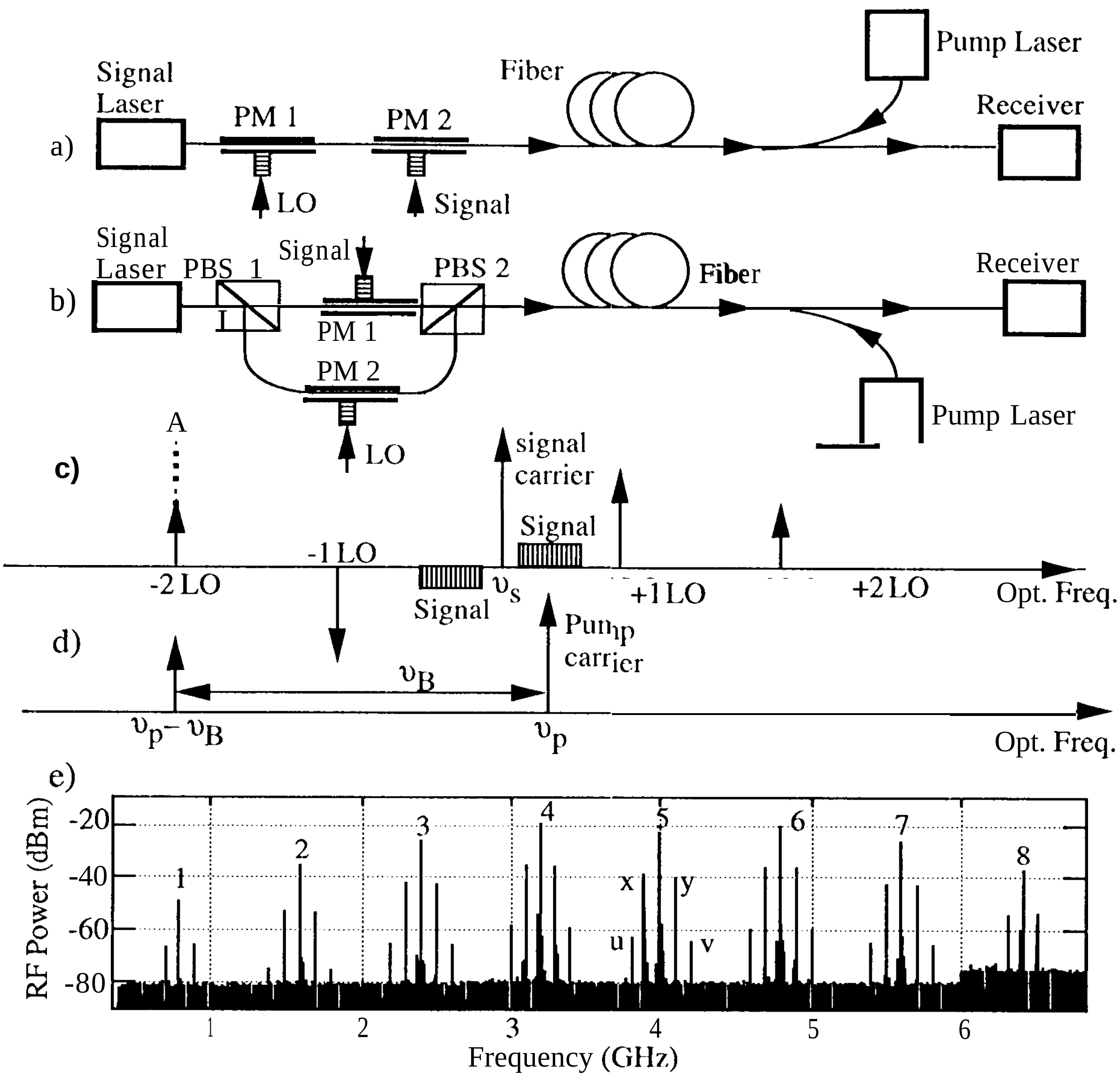

Fig. 3

Yao, "Phase to amplitude modulation conversion . ..."

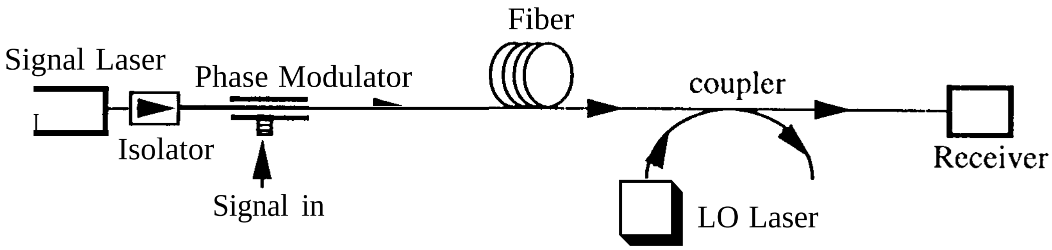

Fig. 4

Yao, "Phase to amplitude modulation . . . ..."