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Numerical Investigation of Brillouin Based Double Sideband Amplification for Millimeter-Wave Generation

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***Abstract* - We show that pump power fluctuations have no impact on the phase noise of millimeter wave signals in Brillouin based double sideband amplification systems. Hence, high quality carriers can be generated.**

I. Introduction

The generation of millimeter waves (mm-waves) is the basis for Radio over Fiber systems which offer the opportunity to combine the mobility of wireless networks with the huge bandwidth of optical fibers. A wireless data transmission of 10 Gb/s in the 120 GHz-Band based on mm-wave photonic techniques was shown, for instance [1].

There are very high requirements for carrier signals in wireless communication systems. Beside frequency stability and a narrow bandwidth, a low phase noise is necessary, because it is an important criterion for the use of different modulation formats in communication systems [2, 3].

For the generation of mm-waves in an optical fiber many possibilities have been proposed so far. The setup simulated in this article uses two sidebands of a frequency comb which are filtered and amplified by stimulated Brillouin scattering (SBS) [4]. Due to SBS a strong pump wave in an optical fiber induces an electrostrictive acoustic wave which propagates in the pump wave's direction. Because of the relative velocity between the pump and the acoustic wave, the backscattered Stokes wave is down shifted in frequency. Due to the superposition principle, the pump wave amplifies a counter propagating signal wave. We use two independent pump sources to amplify two sidebands of a frequency comb. The mm-wave carrier is generated in the photodetector by the beating of the two amplified sidebands. The experimental setup is discussed in detail in Ref. [5].

With an increasing number of waves in the amplification process and massive changes of the intensity of the involved waves the probability of an impact of the nonlinear optical effects of Self Phase Modulation (SPM) and Cross Phase Modulation (XPM) on the phases of the waves is very high. Due to the generation process, different and inconstant phaseshifts lead to an increase of the phase noise of the mm-wave carrier. In this article, we investigate the phaseshift in common and the impact of pump power fluctuations on the phase difference between the signal waves.

II. Theory

For a setup of two pump waves and two signal waves the differential equation system (DES) in (1) describes the amplification process due to the SBS and the impact of SPM, XPM and SBS on the phases of the four different waves [4].

$$\begin{aligned}
\frac{\partial E_{P1}}{\partial z} &= -\left[\frac{g_B\alpha_a}{4A_{eff}}\Delta k_{eR1}P_{S1}+\frac{\alpha}{2}\right]E_{P1} \\
&\quad -j\left[\frac{g_B\alpha_a}{4A_{eff}}\Delta k_{eI1}P_{S1}+\gamma\Big(P_{P1}+2P_{S1}+2P_{P2}+2P_{S2}\Big)\right]E_{P1} \\
\frac{\partial E_{S1}}{\partial z} &= -\left[\frac{g_B\alpha_a}{4A_{eff}}\Delta k_{eR1}P_{P1}-\frac{\alpha}{2}\right]E_{S1} \\
&\quad +j\left[\frac{g_B\alpha_a}{4A_{eff}}\Delta k_{eI1}P_{P1}+\gamma\Big(P_{S1}+2P_{P1}+2P_{P2}+2P_{S2}\Big)\right]E_{S1} \\
\frac{\partial E_{P2}}{\partial z} &= -\left[\frac{g_B\alpha_a}{4A_{eff}}\Delta k_{eR2}P_{S2}+\frac{\alpha}{2}\right]E_{P2} \\
&\quad -j\left[\frac{g_B\alpha_a}{4A_{eff}}\Delta k_{eI2}P_{S2}+\gamma\Big(P_{P2}+2P_{P1}+2P_{S1}+2P_{S2}\Big)\right]E_{P2} \\
\frac{\partial E_{S2}}{\partial z} &= -\left[\frac{g_B\alpha_a}{4A_{eff}}\Delta k_{eR2}P_{P2}-\frac{\alpha}{2}\right]E_{S2} \\
&\quad +j\left[\frac{g_B\alpha_a}{4A_{eff}}\Delta k_{eI2}P_{P2}+\gamma\Big(P_{S2}+2P_{P1}+2P_{S1}+2P_{P2}\Big)\right]E_{S2}
\end{aligned} \quad (1)$$

with

$$\Delta k_{eR1,2}=\frac{v_a^2\alpha_a/2}{(v_a\alpha_a/2)^2+(\omega_{S1,2}-\omega_{S1,2\,max})^2} \quad (2)$$

and

$$\Delta k_{eI1,2}=\frac{v_a\left(\omega_{S1,2}-\omega_{S1,2\,max}\right)}{(v_a\alpha_a/2)^2+(\omega_{S1,2}-\omega_{S1,2\,max})^2}\,. \quad (3)$$

$E_{P1,2\,S1,2}$ is the electrical field of the pump and signal waves and $P_{P1,2\,S1,2}$ is the power of the waves. A_{eff} is the effective core area, α is the attenuation of the optical waves, α_a is the attenuation of the acoustic wave and v_a it's velocity in the fiber material. The maximum Brillouin gain coefficient is written as g_B and γ is the nonlinear coefficient. $\omega_{S1,2max}$ determines the frequency where the Brillouin gain reaches its maximum and $\omega_{S1,2}$ is the frequency of the counter propagating signal wave. The real parts in the DES are responsible for the alteration of the amplitudes of the four waves. The first terms describe the energy transfer between pump and signal waves and the last term is the attenuation in the fiber. The imaginary parts describe the alteration of the phases of the involved waves. The first term in the imaginary part is responsible for the phaseshift by SBS. However, in the gain maximum the influence of the SBS on the phases of the waves is zero, as can be seen in (3). The term which is accompanied with γ describes the SPM in the first part and the XPM in the other three parts. A comparison between the second and the fourth equation of the DES shows, that the influence of the pump waves on the phases of the signal waves is identically. The only reason for a phase difference between the signal waves can be found in unequal signal powers, for instance caused by different pump powers.

III. Simulation

For the calculation of the signal output power at a specific fiber length the simulation results are exactly the same as in Ref. [6]. In the case of equal pump powers and equal signal powers the influence of SPM and XPM on the phases of the signal waves is the same.

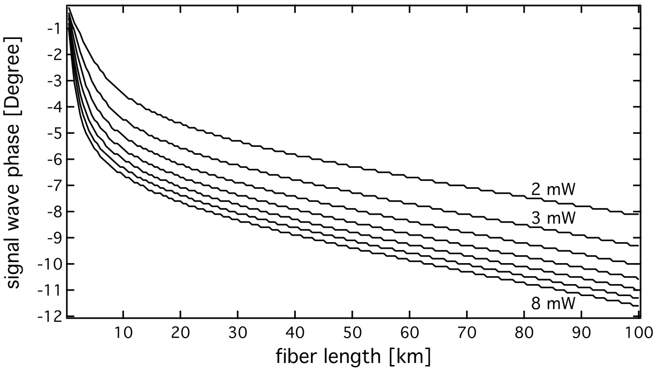

Fig. 1: Output signal wave phase as a function of the fiber length for different pump powers

The phaseshift increases with an increasing pump power, but for high pump powers the amplification and therefore the phaseshift will be saturated (Fig. 1).

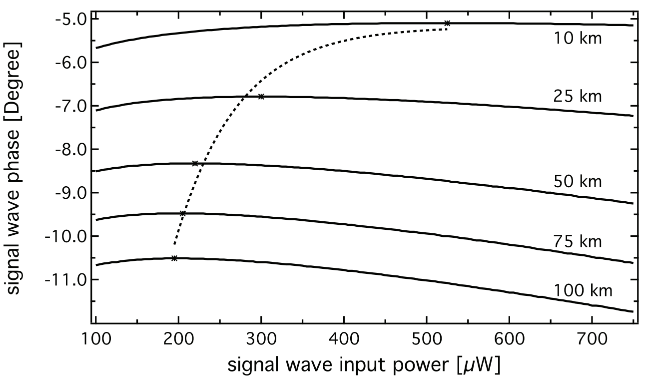

Fig. 2: Output signal wave phase as a function of the signal wave input power for different fiber lengths

A rising input power of the signal waves leads to smaller phaseshifts until a minimum is reached then the behaviour is similar to the case of increasing pump powers (Fig. 2).

The intensity at the photodetector can be written as

$$I \propto E_{S1} E_{S2} \cos\left[(\omega_{S1} - \omega_{S2})t + \varphi_{S1} - \varphi_{S2}\right] \quad (4)$$

with $\varphi_{S1,2}$ as the phase of the signal waves. The frequency difference between the signal waves is the intended mm-wave. In the case of fluctuating pump powers Fig. 3 shows the phase difference between the signal waves. It can be seen that a pump power difference of 1 mW causes a maximum phase difference of approximately 0.05°.

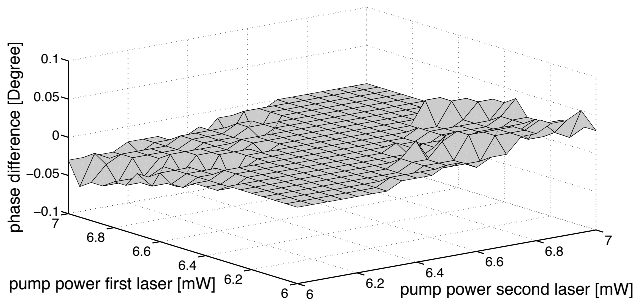

Figure 3: Output signal phase difference as a function of a pump power fluctuation of 1 mW for both pump lasers

IV. Conclusion

The Simulation shows that the additional phaseshift caused by SPM and XPM is lower than 10° for a fiber length of approximately 75 km. Additionally, it is possible to determine a signal input power that causes a minimum phaseshift at a specific fiber length. The phase difference caused by pump power fluctuations can be neglected due to the predictions in Ref. [4]. Hence, neither stochastic fluctuations nor the nonlinear effects of SPM and XPM are sources for an additional phase noise of the generated mm-wave signal.

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