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Full Pump Energy Conversion at Parametric Amplification

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Abstract. The full conversion of the modulated wave energy is shown to be possible and can be reached at mutually simple conformity between the spatial-temporal modulation forms of interaction waves.

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A characteristic peculiarity of the process of three frequency parametric wave interaction at high energy exchange is an alternate energy transfer from the pump wave to the parametric ones and vice versa. During this process there occurs either a confluence of two low-energy quanta into one higher-energy quantum, or a decay of one high-energy quantum in two lower-energy ones. Schematically these two processes can be represented as follows:

$$\text{a) } \omega_1+\omega_2\rightarrow\omega_3, \quad \text{b) } \omega_3\rightarrow\omega_1+\omega_2, \tag{1}$$

where $\omega_3>\omega_2\geqq\omega_1$ are the frequencies of the interacting waves.

Upon solving the problem of high efficiency cascade harmonic generation by a high-power wide apertured Nd-laser it was found that creation of an optimum sum-frequency generation regime demands complete spatial and temporal conformity of the modulations of the mixing waves with frequencies ω_1 and ω_2 accordingly [1]. This condition follows from the Manley-Rowe relations, which mean the conservation of photon density at every point of space and every moment of time in the nonlinear wave interaction area. In this case, there is a possibility, in principle, of full conversion of the pump wave energy to the sum-frequency wave.

For the second type of process (1b) and in particular at the light parametric amplification, the full conversion of the pump wave energy (the frequency of the pump wave is ω_3) to the waves with frequencies ω_1 and ω_2 is considered to be impossible in principle if the modulation form of interacting waves differs from a right-angle form, i.e. if the interacting waves are not in a plane [2].

The energy conversion from pump wave to amplified parametric waves in the process of the second type (1b), in spite of the process (1a), takes place in a finite distance and reverses when the energy of the wave with frequency ω_3 is exhausted. Hence, for real waves with spatial modulations, the optimum regime is such that the maximum energy conversion comes simultaneously for every point of the beam and the pulse. This is unattainable for identical wave modulation forms at the entrance in nonlinear media. In this paper such a regime is shown to be possible if the waves with frequencies ω_i do not have identical initial spatial-temporal forms in the second type (1b) of process. It is naturally assumed that their form must be similar to the finite modulation form of the wave received in the interaction (1a). In this case the processes (1a) and (1b) are mutually reversed. The wave profiles by which the processes (1a) and (1b) are mutually reversed would be called interadditional to each other.

The interaction process is investigated with the nonlinear wave equations [3]:

$$\frac{dA_1}{dz}=-\gamma_1A_2A_3\sin\theta,$$

$$\frac{dA_2}{dz}=-\gamma_2A_1A_3\sin\theta,$$

$$\frac{dA_3}{dz}=\gamma_3A_1A_2\sin\theta,$$

where A_i and φ_i are the magnitudes and phases of the interacting waves, $\theta = \varphi_3 - \varphi_2 - \varphi_1 = \pm\frac{\pi}{2}$ and γ_i is the nonlinear coefficient.

The particular solutions of this set of equations are: ($\omega_1 = \omega_2$, $\gamma_1 = \gamma_2 = \gamma_3 = \gamma$, $\theta = -\frac{\pi}{2}$)

$$A_{1,2} = \frac{A(r,t,0)}{\sqrt{2}\cosh[\gamma A(r,t,0)(\xi_0 - z)]}, \tag{2a}$$

$$A_3 = A(r,t,0)\tanh[\gamma A(r,t,0)(\xi_0 - z)], \tag{2b}$$

where $A(r,t,0)$ is the pump wave distribution profile in the beginning of the interaction, t the temporal coordinate, r the coordinate in the plate that is perpendicular to the axis of the beam spreading z, and ξ_0 an arbitrary constant.

The expression (2) describes the parametric amplification regime when the signal and idler wave energy are equal. At the point $z = \xi_0$ the magnitude $A_3 = 0$ is equal to zero for every point of the beam and the pulse simultaneously. In this paper the full energy conversion from the pump wave to parametric waves is shown to be possible for any form of the pump wave modulation. The only requirement for this is that the process (1b) is the reverse of the process (1a). Hence at $z = 0$ and for arbitrary ξ_0 the expressions (2) set the profile form of the interacting waves. In the case when the pump wave amplitudes are much larger than the signal wave, A_3 is approximately equal to $A(r,t,0)$, i.e. the profile described by (2a) is additional to the distribution profile $A(r,t,0)$. When the energies of the signal and idler waves are not equal, the general expression (2) is very complicated but can be used in this case if the initial energies of the waves are small.

The interadditional profiles of the radiation modulation for the process of the parametric amplification is shown in Fig. 1. The modulation profile of the pump wave is determined by the formula:

$$A(r,t,0) = A_0 \exp[-r^N - t^M]; \tag{3}$$

at different values of the indexes N and M of the hypergaussian function, the interaddition profile is calculated with the formula (2).

The parametric amplification process in the pump radiation with the hypergaussian modulation form ($N = 6$, $M = 6$) was calculated for two cases (Fig. 2): 1 – for a signal wave with interadditional profile (Fig. 1b), 2 – for a hypergaussian modulation of the signal wave. The signal wave energy was taken in the calculations to be three orders less then the pump energy. It is seen from Fig. 2, that the full conversion of the pump energy to amplified waves is reached only for

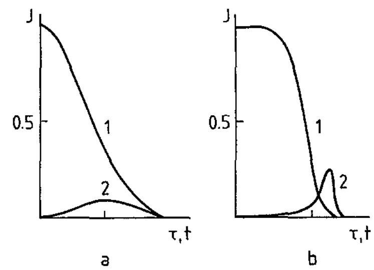

Fig. 1. The spatial-temporal intensity distribution of the pump wave (curve 1) and signal wave (curve 2) with interadditional profiles. The pump wave distribution is determined with the function (3): constants $N = 2$, $M = 2$ (a); $N = 6$, $M = 6$ (b). I is the radiation intensity

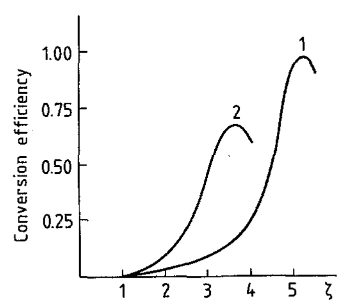

Fig. 2. The dependence of the conversion efficiency of pump wave energy to parametric waves on reduction length $\xi = \gamma A_0 z$

the interadditional form of modulation (curve 1). When the initial forms of the wave modulations are the same (curve 2) the processes (1a) and (1b) are not mutually reversed and the full conversion is not reached in spite of the fact that the forms of the interacting waves are nearly right angle. For the waves with gaussian forms of modulation the energy exchange process is far more limited.

Thus, there is, in principle an opportunity for full energy conversion from the pump wave to parametric waves provided that the modulation forms of the interacting waves are interadditional.

References

1. A.A. Gulamov, E.A. Ibragimov, V.I. Redcorechev, T. Usmanov: Sov. J. Quant. Electron. **10**, 1305 (1983)
2. R. Danielius, A. Piskarskas et al.: *Optical Parametric Oscillators and Picosecond Spectroscopy* (Vilnius, Mokslas 1983)
3. J.A. Armstrong, N. Bloembergen, J. Ducuing, P.S. Pershan: Phys. Rev. **127**, 1918 (1962)