Higher Order Effects in Ultra-broadband Multi-frequency Raman Generation

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Introduction

Ultra-broadband Multi-frequency Raman Generation (UMRG) is one of the most novel nonlinear optical processes to have emerged over the last few years. With H_2 gas as the Raman medium, our analyses have predicted that nearly 50 distinct frequencies of comparable energy may be generated [1-4)]. More recent calculations for UMRG in air at atmospheric pressure, have predicted that beams containing around 150 waves may be attained [5)]. Experimental results, that support our overall predictions, are appearing in the literature. However, in some configurations, effects which are additional to the main UMRG process also come into play. We have investigated a range of such higher order effects and their implications for the efficiency of ultra-broadband light generation. We outline here results dealing with two particular higher order effects: competing nonlinear processes and detuning of the UMRG pumps from the Raman resonance of the medium.

Results

Our model equations have been generalized to incorporate a *non-parametric* competing signal and a quantitative study undertaken of its affect on the primary UMRG process. An effective gain-length product for the parasitic process, Z^{eff}, was introduced and a simple analytical model developed for the case of competing processes arising from background noise or amplified spontaneous emission. Model predictions were found to be in good agreement with full numerical simulations, and showed that the efficiency and character of UMRG can effectively drive such parasitic processes below threshold, $Z^{eff} < Z^{th} = 25$ (see figure 1). Moreover, multi-frequency conversion was also found to be robust when competing signals grew from a strong seed, as could arise from the scattering of a UMRG pump beam [6)].

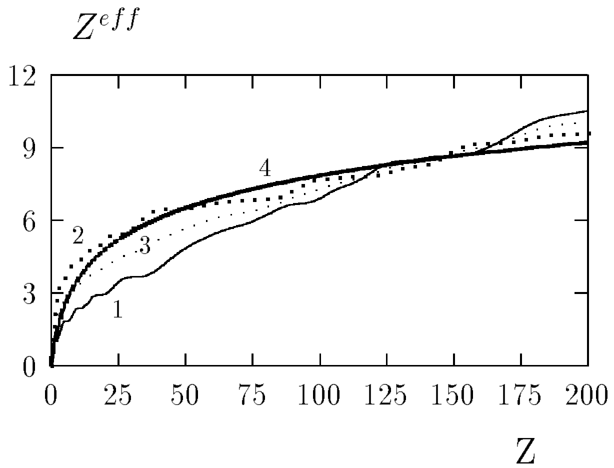

Figure 1. The effective gain-length, Z^{eff}, for competing processes as a function of normalized distance, *Z*. Curves 1-3 are from simulation data while curve 4 is the analytical model

A second key issue is the effectiveness of experimental configurations in which independent oscillator/amplifier chains generate the two-colour pumping for UMRG. In this case, the pumping may not be exactly tuned to the Raman resonance of the nonlinear medium. Thus, detuning has been incorporated into the model equations and analytical and numerical investigations have been undertaken.

For cases of negligible dispersion, we derived an exact analytical solution for the medium polarization wave *P*. This wave defines the parametric gain in the system which, in turn, is directly proportional to the bandwidth generated. We found that this analysis accurately predicts new qualitative and quantitative features of bandwidth generation which arise from detuning of the pump beams (see figure 2).

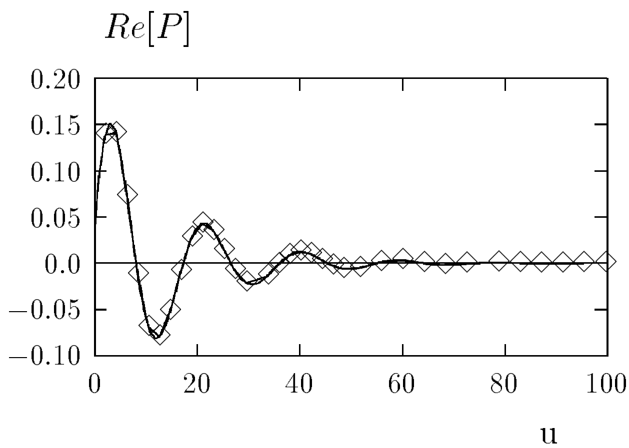

Figure 2. Comparison of analysis and simulation data for the evolution of the real part of the polarization wave when detuned pump beams are employed (*u* is the propagation distance)

While we have shown that non-parametric competing effects need not present any problems, it is also plausible that frequencies of the UMRG spectrum could *parametrically* generate a parasitic wave. Our results on detuning effects have been used to assess this possibility and we found that UMRG can also be robust in this respect.

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