Optimal conversion in the depleted stage of modulation instability

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The dynamics of Modulation Instability (MI) can be well described by the truncated three wave mixing model [1]. The flow of power from the pump to the signal-idler pair (and harmonics) is recurrent [1,2], being inverted after the characteristic distance Z_c where the depletion is maximum. Such maximum depletion depends strongly on the frequency detuning of the signal. Surprisingly, the frequency f_{MI} of the maximum MI gain (nonlinear phase-matching) do not yield the most favourable conversion (strongest depletion) [1]. Vice versa the theory predicts that the depletion increases at lower frequency detunings reaching 100% for $f_d = f_{MI}/\sqrt{2}$. While this has been theoretically predicted a while ago, no experimental demonstration of this behavior has been reported yet. In this work, we experimentally report the first experimental observation of this fundamental phenomenon.

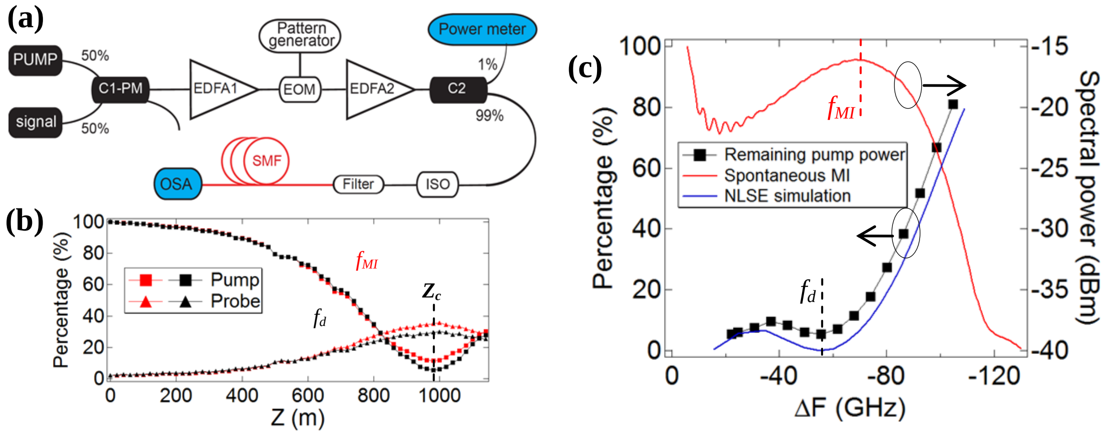

Fig. 1 (a) Experimental setup. C1-PM, polarization maintaining coupler; EDFA, erbium-doped fiber amplifier; EOM, electro-optic modulator; C2, coupler; ISO, isolator; SMF, Corning 1.1 km single mode fiber; OSA, optical spectrum analyzer. (b) Longitudinal evolution of the pump and probe powers with f_{probe} = 68 GHz (black squares and triangles) and f_{probe} = 55.9 GHz (red squares and triangles). (c) Left axis: experimental percentage of remaining energy in the pump (black squares) and simulated one (blue line). Right axis: spontaneous MI spectrum recorded without probe.

We used a similar experimental set-up (Fig. 1(a)) to that of Ref. [2]. A strong CW-pump (1560 nm) and a weak CW-probe are combined and intensity modulated to generate 12 ns square pulses at 5 MHz repetition rate. For increasing their peak power, the pump pulses are amplified by an erbium-doped fiber amplifier (EDFA2) before being launched into a 1.1 km long Corning SMF28 fiber. To characterize the MI dynamics, we performed a cutback experiment and recorded the output spectra every 20 m. Red squares and triangles in Fig.1 (b) show the longitudinal evolution along the fiber of the pump and the probe power for f_{probe} = 68 GHz. This value corresponds to the frequency shift for peak MI gain (see the red curve in Fig. 1(c) showing the spontaneous MI gain spectrum). As expected, the pump is only partially depleted at Z_c = 980 m: about 10% of energy is left in the pump, before growing up again. Black squares in Fig. 1(c) display the evolution of minimum pump energy for different pump-signal frequency shifts. The absolute minimum is only 5% (see the black curve in Fig. 1(c)), and it is obtained for a frequency shift of 55.9 GHz, in good qualitative agreement with the theoretical value ($f_{MI}/\sqrt{2}$ = 48.1 GHz). We compared the experimental results with the numerical solutions of the GNLSE (blue curve in Fig. 1(c)) for a monochromatic pump wave. A good quantitative agreement in the maximum depletion frequency is achieved, although simulations predict zero residual pump energy. Numerical simulations show that the residual pump energy is due to averaging over the nearly square power profile of the pump pulses.

In conclusion, we report the first experimental demonstration of maximum pump depletion in the nonlinear regime of modulation instability process [1]. As expected from theory, the minimum is obtained very close to the theoretical value of $f_{MI}/\sqrt{2}$, with a residual pump energy as low as 5%.

References

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