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OPTICAL SWITCHING USING SECOND ORDER NONLINEARITIES

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Abstract

It is shown that single–step phase–matched parametric conversion, seeded with small amounts of second harmonic (SH), can yield nonlinear pump phase–shifts, and that the output state is extremely sensitive to the phase of the injected SH.

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Recently, the use of a cascaded second order nonlinearity has been proposed for all-optical switching [1]. Standard coupled–wave theory of second-harmonic generation (SHG) shows that the pump wave undergoes a nonlinear phase shift when the SHG process is phase–mismatched. This has led to the proposal of a number of novel switching devices, including a push-pull Mach–Zehnder switch [2]. Looking at the origins of linear and nonlinear polarization, a common feature, if the refractive index is to change, is that a frequency component in the driving fields should appear in the resulting nonlinear polarization. In the case of the optical Kerr effect, $P_\omega^{(3)} = \chi^{(3)}\{\omega;\omega,\omega_1,-\omega_1\}E_\omega E_{\omega_1} E^*_{\omega_1}$. In a similar way, phase changes also appear in the pump wave during degenerate parametric frequency down-conversion: $P_\omega^{(2)} = \chi^{(2)}\{\omega;2\omega,-\omega\}E_{2\omega} E^*_\omega$, but none occur during frequency doubling, i.e., $\chi^{(2)}\{2\omega;\omega,\omega\}E_\omega E_\omega$ contains no term of type $P_\omega^{(2)}$. Added to the well-known fact that both up– and down–conversion can occur under phase-matched conditions (the dominant process depending on the relative phase, a balance occurring at the nonlinear eigen-mode point[3]), it does not seem necessary to demand phase mis-matching to obtain a nonlinear phase change in the pump light.

In the cascaded process, the SH is generated and gradually gets out of phase owing to differences in phase velocity between pump and SH. This means (since the direction of conversion depends on the relative phase) that down–conversion begins to appear increasingly as the phase mis–match increases, which yields, according to the argument above, a

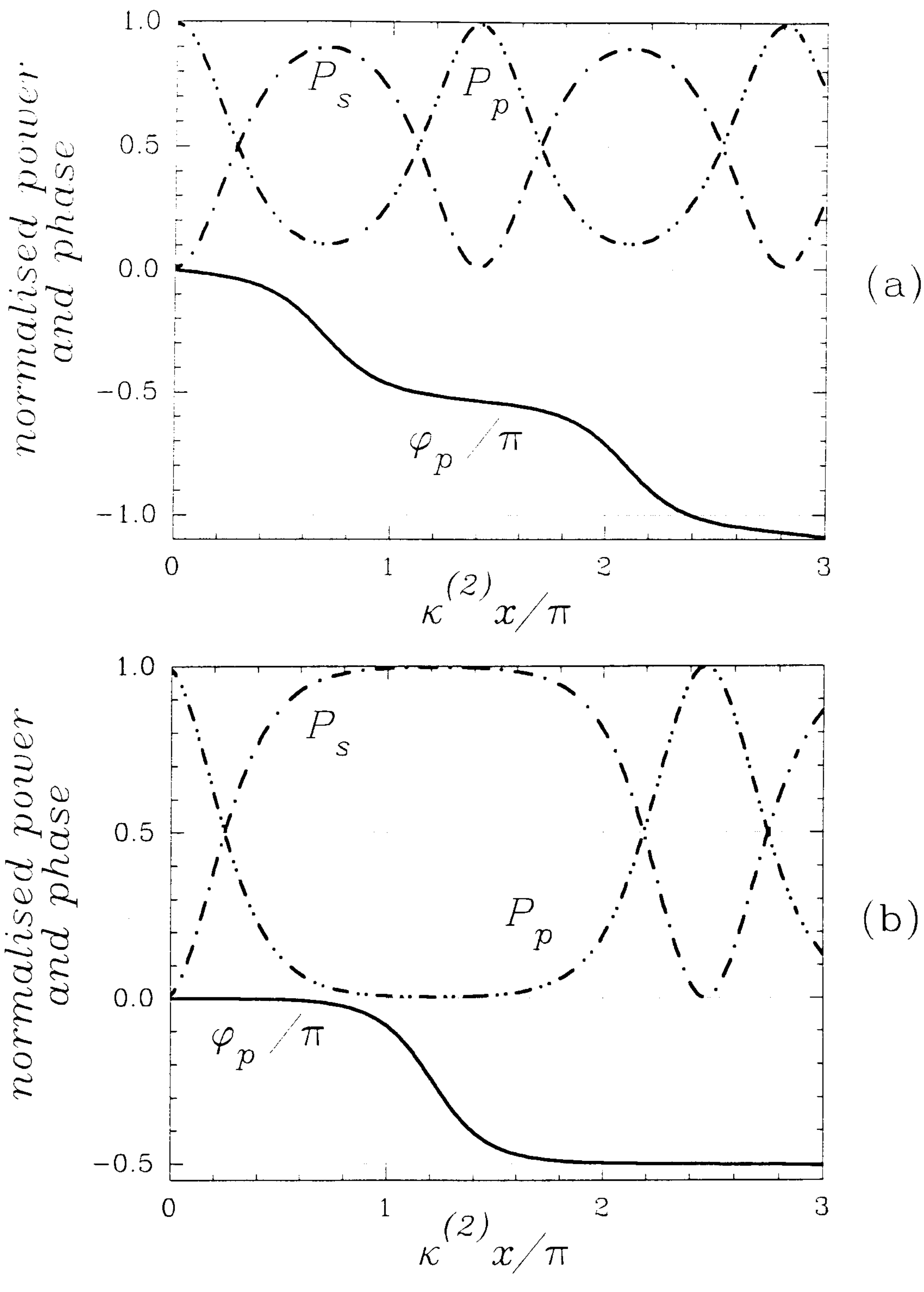

Figure 1 **Normalised pump, SH and pump phase evolution with distance for exact phase-matching and 1% injected SH signal at $\kappa^{(2)}L = 3\pi$ for (a) $\psi = 0$ and (b) $\psi = 0.49\pi$. In the absence of the 1% SH seed, the pump phase change is zero. Note that, as expected, the rate of nonlinear phase change with distance is greatest when the down-conversion process is dominant.**

nonlinear phase change in the pump wave. This also suggests that pump phase changes may be induced at exact phase–matching if both pump and SH are launched together with an appropriate relative phase. To illustrate this result, I draw upon the distributed feed-forward results in a recent theoretical analysis of reconstruction in nonlinear holograms [3]. Of particular interest are the conserved quantities:

$$\Gamma \quad = \quad 4\kappa^{(2)}\sqrt{P_s P_p}\cos\psi - \vartheta(P_p - P_s) \tag{1}$$

and $P_p + P_s = 1$, which represents power conservation, P_p and P_s being the normalised powers of the pump and SH. ϑ describes dephasing, $\kappa^{(2)}$ is the nonlinear coupling constant (proportional to the square root of the incident power) and $\psi = \phi_s - 2\phi_p$ is the relative phase between SH and pump. From Equation (14) in [3], and using (1), the evolution of the pump phase ϕ_p with distance x is easily shown to be described by:

$$\frac{\partial \phi_p}{\partial x} \quad = \quad -\frac{\vartheta}{2} + \frac{(\vartheta - \Gamma)}{4P_p(x)}. \tag{2}$$

The only varying quantity on the right hand side of this equation is the pump power P_p, and Γ is set by the boundary conditions. If the incoming SH is zero (as in [1]) then inexact phase matching is essential ($|\vartheta| > 0$) for a nonlinear change in pump phase. If it is not, then even when $\vartheta = 0$ it is possible to obtain a nonlinear phase change in the pump wave provided the relative phase ψ is not equal to $\pi/2$.

Some solutions of (2) for exact phase-matching and only 1% injected SH are given in Figure 1. Next, keeping the SH seed power at 1% (for $\vartheta = 0$) while its relative phase is varied (Figure 2), the effects are dramatic: the output slews rapidly between 100% pump (at 0.26π) and 100% SH (at 0.5π). This result may have applications in nonlinear mode–locking of lasers and in clarifying the growth of self-organised $\chi^{(2)}$ gratings in optical fibres.

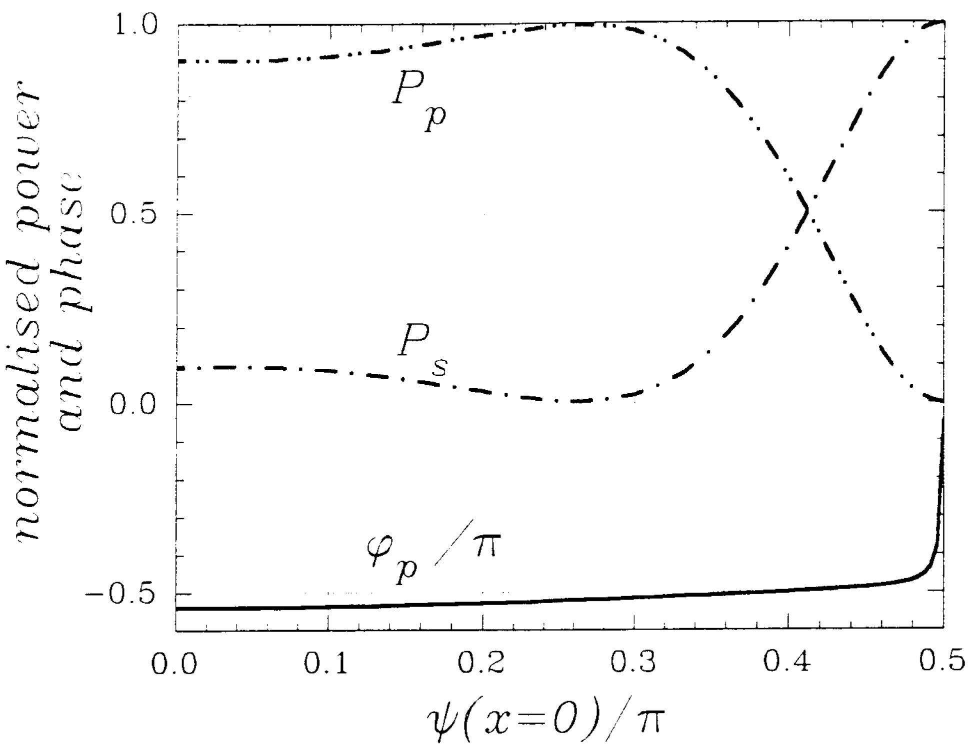

Figure 2 The pump and SH powers and pump phase at the output plane $\kappa^{(2)}L = 3\pi/2$ of a SH generator, plotted as a function of the relative phase ψ at the input surface $x = 0$ for an injected SH power of 1% of the pump. The output swings from zero to complete SH conversion between $\psi = 0.26\pi$ and 0.5π.

References

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