Gamma-Echo in Optical Domain

R N Shakhmuratov[1]

[1]*Nonlinear Optics, Kazan Physical-Technical Institute, Sybirski trakt 10/7, 420029, Kazan, Russia.*
Contact Phone: +79600367595
Contact Email: shakhmuratov@mail.ru

Interaction of a coherent field with resonant particles demonstrates many interesting transient phenomena. Among them are transient nutation (TN), free induction decay (FID), and gamma-echo (GE) induced by weak fields propagating in a thick resonant medium in the linear-optics regime. TN and FID show that coherent forward scattering of the field by resonant particles forms a field that propagates the same direction as an incident field and has opposite phase. This field interferes destructively with the incident field resulting in its attenuation to a constant value expected from Beer's law. Formation of this field takes time and seen as transient nutation of a week step-modulated field after propagating in a thick resonant medium [1-3]. Sudden switch off of the incident field gives a radiation flash, FID, which is just the field scattered by resonant particles [2,3]. For thick samples the intensity of the flash is close to the intensity of the incident field and decays with the rate defined by homogeneous dephasing rate γ and optical thickness parameter $D = \alpha L$, where α is absorption coefficient and L is the length of resonant medium.

Gamma-echo is observed after an abrupt jump of the field phase by π as a radiation flash emitted by an optically thick resonant absorber. GE was discovered in 1991 for gamma-photon wave packets after an abrupt displacement of a radiation source on a half wavelength with respect to a resonant absorber [4]. Then, GE was theoretically predicted [3] and experimentally observed [5] in optical domain. GE allows to generate a sequence of short pulses if π-shifts of phase follow periodically, see Figure 1(b). Before the phase jump, the forward scattered field $E_{\rm scat}$ interferes destructively with the incident field $E_{\rm in}$. If time intervals between the phase jumps is long enough and resonant absorber is optically thick, intensity of the field $I(t)$ between the phase jumps is reduced to the level $I(t) = \exp(-D)I_0$, where I_0 is the intensity of the incident CW field. Immediately after the abrupt phase jump of the incident field by π the fields $E_{\rm in}$ and $E_{\rm scat}$ interfere constructively resulting in the radiation flash with maximum intensity $I_{\max} = (4 - 2e^{-D/2} + e^{-D})I_0$. Such a series of flashes are shown in Figure 1(b) for the instantaneous phase jumps. After each phase jump new coherently scattered field with phase opposite to the incident field develops resulting in their destructive interference. This process is seen as attenuation of the field emerging from the absorber. Decay of this field intensity is approximated by the function $e^{-2\gamma t}J_0^2(\sqrt{2\gamma t D})$, where $J_0(x)$ is the zero-order Bessel function and time

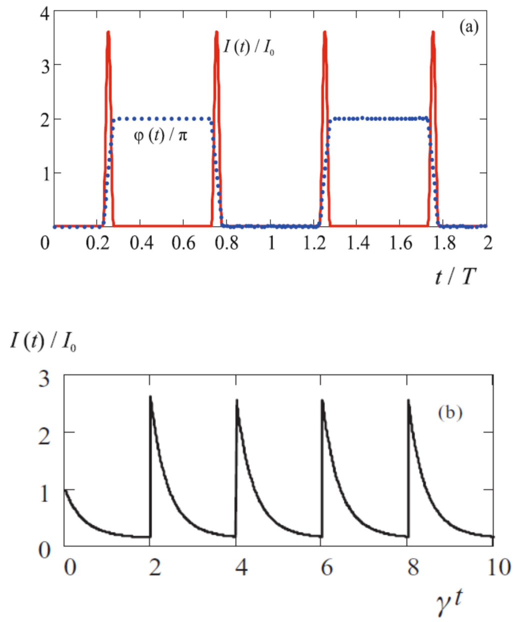

Figure 1: (a) Phase shifts by 2π of $\varphi(t)$ according to a binary sequence with a period T (blue dots) and generated sequence of pulses (red solid line) in resonant absorber of optical thickness $D = 15$. (b) Pulse sequence generated in resonant absorber of optical thickness $D = 2$ by a sequence of π phase shifts repeated with a period $2T_2 = 2/\gamma$, where T_2 and γ are homogeneous decay time and decay rate of the atomic polarization, respectively

t is counted from the moment of the phase jump. Roughly, the decay time of the flash can be estimated as $T_{\rm dec} = 2T_2/\sqrt{D}$, where $T_2 = 1/\gamma$ is a homogeneous decay time of atomic polarization. The decay time $T_{\rm dec}$ defines the formation time of a new scattered field with the opposite phase to the phase shifted incident field. Period T of the π-shifts of the incident field phase must be larger than $T_{\rm dec}$ to observe pulses. Therefore, the time intervals between phase shifts cannot be shorter than $T_{\rm dec}$, which means that the spectrum of the CW field with a periodically changing phase must be narrower than the linewidth of the absorber broadened by optical thickness.

Recently, it was proposed to circumvent this limit by increasing the phase shifts to 2π [6], see Figure 1(a) where the field phase $\varphi(t)$ (dotted blue line) periodically jumps from 0 to 2π and back from 2π to 0. Phase increases (decreases) linearly in short time intervals τ, which are much shorter than the period T of the phase shifts. In this case pulses appear when $\varphi(t)$ crosses the value π and destructive interference between the incident and coherently scattered field changes to constructive one. Between the phase shifts the coherently scattered field has opposite phase with respect to the incident field. When $\tau \ll T$, the coherently scattered field has time to fully develop during $T_{\rm dec}$, which can be much longer than T, since the phase jumps in short time intervals do not affect appreciably time evolution of the coherently scattered field. However, its amplitude is slightly reduced by a factor of $1 - 2\tau/T$ because of the phase change in short time intervals. As a result, the generated pulses have large intensity, which is $4(1 - \tau/T)^2 I_0$. Their duration (from shoulder to shoulder) is equal to τ and they have symmetric shape for a linear change of phase. The phase modulated field spectrum consists of an equidistant spectral components separated by the frequency $2\pi/T$. Since T can be made much shorter than $T_{\rm dec} = 1/\gamma_{\rm dec}$ (in contrast to the case of π phase shifts), these spectral components are well separated compared with the linewidth of the absorber broadened by thickness. Therefore, removal of the central component by resonant filter or any other spectral filter with comparable spectral width is capable to produce short pulses. Pulse repetition rate in this case can exceed 1GHz and reach 10GHz if phase-shift time intervals τ are short ranging from 10 to 1 ps. These fast phase shifts can be accomplished by electrooptic phase modulators supplied by square wave voltage pulses with steep edges. Technically, Gunn diode or IMPATT diode allow switching in the electrical circuit at a rate of 1 THz.

In this report, generation of pulses with variable time spacing is also discussed. This capability paves the way for time division multiplexing to transmit digital information over a single channel at high speed.

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