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PULSE STIMULATED RADIATION FROM A PLASMA INVOLVING THE SECOND HARMONIC OF THE GYROFREQUENCY

Wilhelm H. Kegel

Technical Report No. 34 October 31, 1966

CALIFORNIA INSTITUTE OF TECHNOLOGY

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If a plasma is excited by two short pulses at the gyrofrequency and its second harmonic, respectively, with a time separation τ, a radiation maximum is predicted to occur at the gyrofrequency a time τ after the second pulse.

We consider a magneto-plasma which is excited by two short microwave pulses, which have a time separation τ. The first pulse is assumed to be at the gyrofrequency, the second at its second harmonic. It is shown that a radiation peak at the gyrofrequency occurs a time τ after the second pulse. This radiation peak is due to the non-linear driving force during the second pulse. This is in contrast to the usual echo, where both pulses are at the gyrofrequency [1-5].

The plasma is considered in the single-particle approach. We account for field inhomogeneities by attributing different gyrofrequencies to different particles. In this model all electrons have at the end of the first pulse (fig. 1a) the same velocity V and the same phase. $V = eE_1^0 t_1/2m$ is given by the strength of the first pulse, E_1^0 being the amplitude of the electric field and t_1 the duration of the pulse. A time τ after the first pulse ($\Delta\omega_c\tau \gg 1$), i.e. at the onset of the second pulse, the electrons are distributed on a circle in the two dimensional rotating velocity space [1] (fig. 1b) due to the differences in gyrofrequency. The second pulse (at $2\omega_c$) induces a quadrupole moment (fig. 1c). If $v(\tau)$ are the coordinates of a given particle in the rotating velocity space at the onset of the second pulse (fig. 1b) and v^* its coordinates at the end of the pulse (fig. 1c), we have in lowest order [6]:

$$v_x^* = v_x(\tau)\,e^{s}; \qquad v_y^* = v_y(\tau)\,e^{-s} \tag{1}$$

with

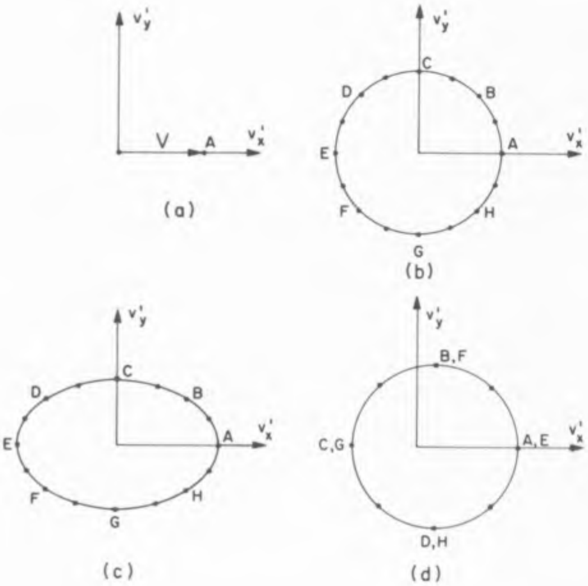

Fig. 1. Distribution of particle velocities in a rotating velocity space a) a the end of the first pulse, b) at the onset of the second pulse, c) at the end of the second pulse, d) at a time τ after the second pulse, the first pulse being at ω_c and the second at $2\omega_c$.

$$s = eE_2^0 t_2/2cm \tag{2}$$

A time τ after the second pulse, a particle which has a phase angle φ at the onset of the second pulse has moved around the origin by another angle $\varphi \pm 2n\pi$. As a result the ellipse in fig. 1c has been transformed into a circle, the center of which is different from the coordinate origin (fig. 1d). This shows that a macroscopic dipole moment has been formed, i.e. there is a radia-

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tion maximum at the gyrofrequency at this time.

For the radiation at the gyrofrequency we have [4,5]:

$$I_c \sim N^2 V^2 \phi_1(t) \tag{3}$$

where N is the number of particles considered and the function $\phi_1(t)$ is given by:

$$\phi_1(t) = \left(\sum_{l=1}^{N} v_l \right)^{-2} \left| \sum_{l=1}^{N} v_l \exp[\mathrm{i}(\omega_c^l t + \alpha_l)] \right|^2 \tag{4}$$

where α_l is the phase of the l-th particle at $t = 0$.

If one determines ϕ_1, for the radiation peak, i.e. for the time τ after the second pulse [6], one obtains on the assumption $s \ll 1$

$$\phi_1(\tau) \approx s^2 \tag{5}$$

(5) gives a finite amplitude of the radiation peak even for $\tau \rightarrow 0$, in contrast to the results one obtains in the case where both exciting pulses are at ω_c [4,5,7].

The conditions for the occurrence of the *usual* echo (both pulses at ω_c) are of two types: a) General conditions: The electron density must be sufficient for the effect to be observed, the initial temperature must be low enough so that the electrons do not drift out of the observation region, the decay time must be sufficiently long, etc. b) Special conditions which give the essential nonlinearity. For the nonlinearity essentially two different mechanisms have been proposed, namely an energy dependent collision frequency [7], and an energy dependent gyrofrequency [4,5]. In order to demonstrate that in a given experiment a given nonlinearity is the echo forming mechanism, one could try to keep the general conditions fixed and change only the special conditions until the echo disappears.

In contrast to the usual echo the new effect discussed in this letter (second pulse at $2\omega_c$) depends on the general conditions only, because the nonlinearity is given in this case by the nonlinear driving force during the second pulse, which does not depend on any plasma parameter. So this effect could be used to check independently of the special conditions, whether the general conditions are fulfilled under given experimental conditions.

If other nonlinearities, such as a velocity dependent gyrofrequency or collision cross-section, are taken into account, further radiation maxima may be shown to occur at the gyrofrequency at times 3τ, 5τ, etc. after the second pulse [6].

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