ON THE SUPRESSION OF ELECTRON PHASE-BUNCHING IN GYRORESONANT INTERACTIONS IN THE MAGNETOSPHERE

F. M. Serra

Centro de Electrodinâmica, Instituto Superior Técnico
1096 Lisboa Codex, Portugal

1. Introduction

The gyroresonant interaction between a whistler mode monochromatic wave and energetic electrons may cause a spatial and temporal coherence of resonant electrons, eventually leading to wave growth and triggering of self-sustained emissions /1/. Using a simple test-particle model we show that a perturbing second wave can destroy the coherence by inhibiting the phase-bunching of the first-wave resonant electrons; this mechanism seemingly underlies several multi-wave supression phenomena detected in VLF wave injection experiments into the geomagnetosphere /2, 3/.

2. Theoretical approach and simulation results

The evolution of test-electrons in the field of two whistler mode monochromatic waves (propagating in the same duct, along the geomagnetic field) is followed through the numerical integration of the equations of motion, using a model for the magnetosphere at L~4 which takes into account the inhomogeneity of the medium /4/.

Fig.1(a) shows the temporal evolution of the phase angle Ψ_1 (between $v_\perp$ and $-B_{w1}$ of 12 electrons initially (5°N) uniformly spaced in their phases with the same pitch angle ($\alpha = \tan^{-1}(v_\perp/|v_\parallel|) = 60^\circ$) and in exact resonance with a single wave $f_1 = 4$ kHz (with amplitude $B_{w1} = 30$ pT, assumed constant during the interaction) propagating against the electrons, from geographic south to north. For the set of trapped electrons (those initially with phases between $-5\pi/6$ and $\pi/3$) a phase-bunching is clearly seen around $\sim -\pi/12$, after a 'bunching time' roughly one fourth the trapping period, $T_B = T_t/4 \sim 2.5$ ms; it recurs periodically (period $\sim T_t/2$) around values approaching $\Psi=0$ as the interaction evolves towards the equator (since the inhomogeneity of the medium decreases).

Fig.1

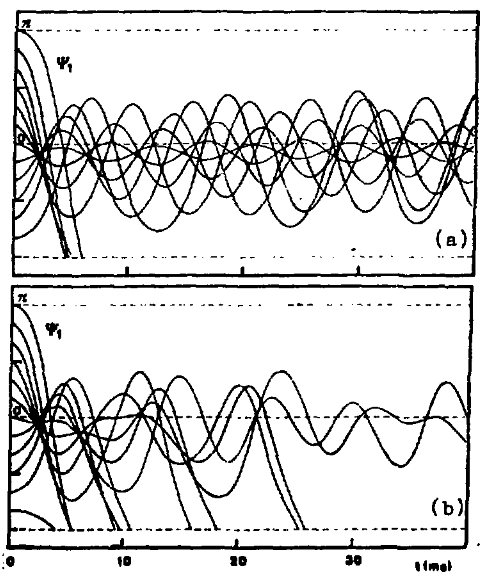


Fig.1(b) shows the evolution of the same set of electrons in the presence of a second wave ($f_2 = 3.955$ kHz, $B_{w2} = 10$ pT) 'switched on' at $t = 0$. As compared with (a), drastic de trapping effects are observed with the consequent degradation of phase-bunching. This behaviour can be understood as due to the fact that the electrons now evolve in a global 'potential' whose local temporal variation is significant within a trapped period of the motion; the chosen frequency separation (Δf = 45 Hz) corresponds roughly to a critical value leading to maximum detrapping effects /4/.

The loss of spatial and temporal coherence of the electrons will correspondingly affect their contribution to a transverse current (which is only one of the components in the total resonance current due to the entire population). In order to estimate this contribution we adapt the 'test-sheet' model for an homogeneous situation /5, 6/ to the inhomogeneity of the medium. In slowly varying conditions the phase behaviour of a single sheet is supposed identical to that of a 'stream' segment (of length ℓ, modelled as a succession of identical sheets separated apart by $\Delta z \ll \lambda$ (wavelength of the wave)) such that all sheets in the stream encounter the wave approximately at the same time; one must therefore compare the time difference ΔT, between the encounters with the wave of the first and last sheets, with some characteristic time of the electron perturbed motion (say T_B). With typical values for magnetospheric parameters at L=4, and f_1= 4 kHz, B_{w1}= 30 pT, we estimate $\Delta T \lesssim \ell/(V_p - V_G) \sim \ell/5\times10^7 ms^{-1}$ (where V_p and V_G are respectively the phase velocity of the wave and the resonance velocity of the electrons); in order to ensure, say $\Delta T \lesssim T_B/10$ one must have $\ell \lesssim 15\times10^3$ m ~ 5λ.

Under these circumstances a single sheet will characterize a stream and the simulation is interpreted as if an apparent rotation of the stream population occurs at a given location instead of the real longitudinal displacement of electrons. The wave induced phase-bunching of the sheet electrons stimulates a net $\langle \underset{\sim}{v}_\perp \rangle$; this can be visualized from the schematic distribution of $\underset{\sim}{v}_\perp$ in Fig.2(b), as compared with the initial uniform distribution (a) (in a plane transverse to the geomagnetic field). The resulting wave-stimulated current associated with a test-sheet (s) with N_s electrons will be

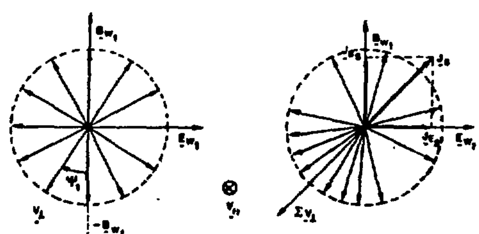
$$J_s = -eN_s \langle \underset{\sim}{v}_\perp \rangle \quad . \qquad (1)$$

The current components (along $\underset{\sim}{E}_w$ and $\underset{\sim}{B}_w$), normalized to $v_\perp$, can be evaluated (respectively) from

$$J_E = \frac{1}{N_s} \sum_{i=1}^{N_s} \sin\left[-\Psi_{1i}(t)\right] \qquad (2)$$

$$J_B = \frac{1}{N_s} \sum_{i=1}^{N_s} \cos\left[-\Psi_{1i}(t)\right] \quad . \qquad (3)$$

Fig.2



(a) (b)

It should be made clear that in fact the test-electrons do not remain at the same plane of the sheet initially considered, as the interaction evolves; this feature should be considered when discussing the validity of the test-sheet approach in an inhomogeneous situation.

As a consequence of the interaction between a test-sheet with 36 electrons (initially uniformly spaced in phase) and the single wave of Fig.1, 25 electrons are stably trapped and 11 are untrapped. The different behaviour of the trajectories for these two distint sets of electrons determine their relative spatial separation, but some spatial coherence within each group is mantained: therefore we assume that the initial test-sheet splits into two: one for the trapped electrons, moving with velocity V_G, the other with the approximately adiabatic $v_{\parallel}$ characterizing the motion of untrapped particles. The previous multi-sheet stream description is valid for each group as all corresponding electrons are included between the first and the last sheets, which is still the case for both populations after 40 ms ($\sim 4T_t$): $\ell_t \sim 3$ km$\sim\lambda_1$, $\ell_u \sim 10$ km$\sim 3\lambda_1$, respectively for trapped and untrapped, roughly satisfying $\Delta T \ll T_B$.

Fig.3

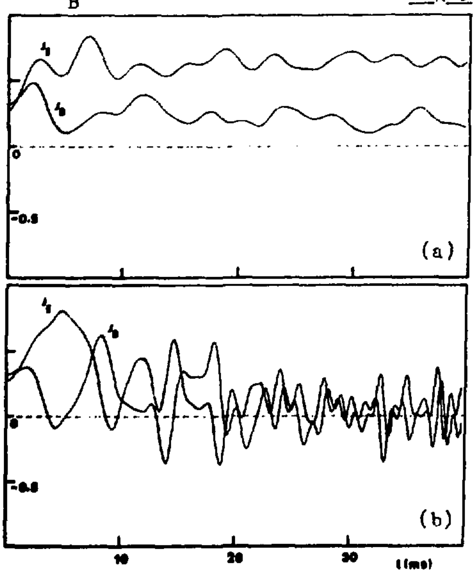


Fig.3(a) shows the separate contribution of the trapped electrons for the resonance current, whose components are evaluated through (2) and (3) (on a plane initially corresponding to the test-sheet at t=0, $z=z(5^{\circ}N)$, and moving with velocity V_G). The presence of the second wave (of Fig.1(b)) strongly affects the current, as can be observed in Fig.3(b); the loss of coherence results from the untrapping of almost all (20 in 25) previously trapped electrons.

3. Concluding remarks

A simple test-particle model for a two-wave – electron interaction is used to evidence the decisive role a perturbing wave may play in the generating mechanism of a first-wave transverse resonance current.The loss of coherence of resonant electrons implies the reduction (or even the supression) of the growth and triggering capabilities of a coherent wave, in agreement with experimental observations of mutual supression phenomena involving two monochromatic waves separated by few tens of Hz /2/. A realistic description accounting for the global electron distribution is beyond the scope of this paper and might eventually be tackled with a self-consistent model currently under study for an interaction with a single wave /1/.

References

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