SELF-GENERATED MAGNETIC FIELDS AND HARMONIC EMISSION

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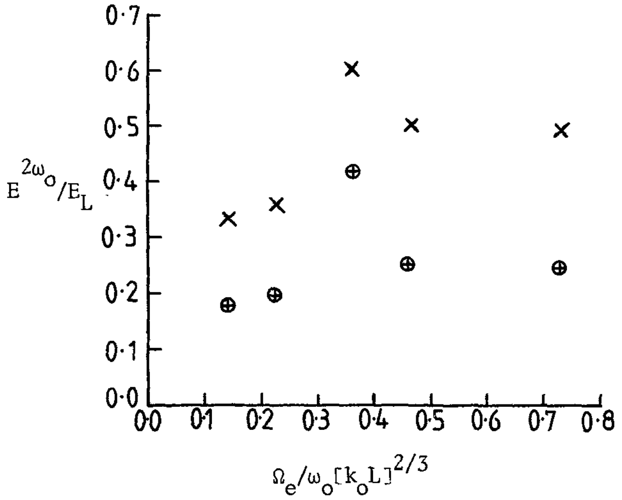
Recent observations of self-generated magnetic fields in plane target experiments [1] with high powered lasers have prompted us to look again at harmonic emission from magnetized plasmas. It is well known from the work of Fidone and his collaborators [2,3] that second harmonic generation in Tokamak plasmas has not only been observed but has proved to be a useful magnetic field diagnostic. In the experiments by Raven and his co-workers, megagauss fields were measured in the quarter-critical density region, from which one might expect that magnetic field strengths close to critical density would be very large indeed - parhaps as big as 10MG - though no measurements have yet been made in this region. In the presence of such strong magnetic fields it has been shown recently that significant absorption of normally incident laser light is possible, together with harmonic generation [4,5]. In this paper we report a theoretical study of harmonic generation together with results obtained from numerical experiments using a $1\frac{1}{2}$-D code, EMPIRE. The computer experiments, in addition to providing information on harmonic emission, also indicate that a strong quasi-static magnetic field is generated in the neighbourhood of the resonance region. This field has been detected in simulations carried out independently [6].

The configuration examined in this work is the following. An electromagnetic wave propagates along Ox and is normally incident on a plasma density ramp. The electric field of the incident wave is aligned along Oy . We shall suppose that a magnetic field B_o is applied along Oz . As the wave propagates into the plasma, the E_y field induces electron oscillations along Oy and the resultant $\underline{v} \times \underline{B}$ force effectively produces particle motion in the direction of propagation. Thus by charge separation along the density gradient, an electrostatic field component E_x is produced. This is of course just the extraordinary mode in the plasma. The interest in this mode stems from the fact that N_R , the density at which the wave resonates at the local upper hybrid frequency, and N_C , the cut-off density, are related by $N_C \simeq N_R[1 - \Omega_e/\omega_o]$, where Ω_e is the electron cyclotron frequency and ω_o , the frequency of the incident wave. Consequently if $\Omega_e << \omega_o$, as is certainly the case in Nd laser produced plasmas, then $N_C \simeq N_R$. We then have a situation analogous to that of obliquely incident radiation in unmagnetized plasmas. The difference between the two cases is that in the latter the separation between the cut-off and resonant densities is governed by the angle of incidence of the wave, whereas in the magnetized plasma considered here, this separation is governed effectively by the strength of the magnetic field. Thus resonant absorption of a normally incident wave is made possible by the magnetic field and has been examined both theoretically and by computer simulations.

This resonance takes the form of a plasma disturbance which produces a large localized oscillating electrostatic field. The rapid spatial variation of this field produces anharmonic oscillations of the electrons, due to their being subjected to varying electric field strengths over their excursion lengths. This electron behaviour may be represented as a series of Fourier modes at $\omega_o, 2\omega_o, 3\omega_o$ ... and these modes then provide a current density source with components at $2\omega_o, 3\omega_o$ .... The particular modes responsible for the generation of the $2\omega_o$ current density are the ω_o and $2\omega_o$ electron oscillations. The former beats with the oscillating electron number density $N(\omega_o)$ to produce a component $eN(\omega_o)V_e(\omega_o)$ while the latter combines with the unperturbed number density to give a term $eN_oV_e(2\omega_o)$. Hence as a direct result of the resonant mechanism a current density $J(2\omega_o)$ is produced which, in turn, provides the source of second harmonic emission.

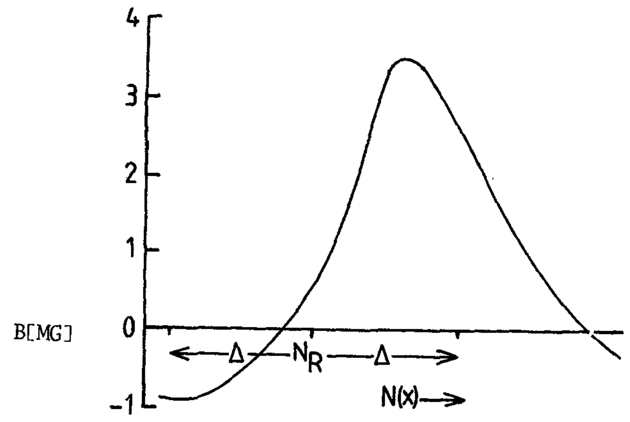
Fig. 1



⊕ - Theory ; X - Computation.

To find the relation between the power in the incident wave and that re-emitted as second harmonic, we have to determine the current density. This is then treated as "free" current and is used as a source term in the second harmonic wave equation. This relationship has been evaluated and Fig. 1 shows a comparison between the theoretical results and those obtained from computer simulations. The parameter on the abscissa is the ratio of the distance between cut-off and resonant layers and the scale of variation of the electromagnetic wave near cut-off; $k_o = \omega_o/c$ and L is the plasma scale length, i.e. the distance between the critical density and the boundary. While there is some discrepancy between the theoretical results and those from the computer experiment, the overall agreement is quite good.

Fig. 2

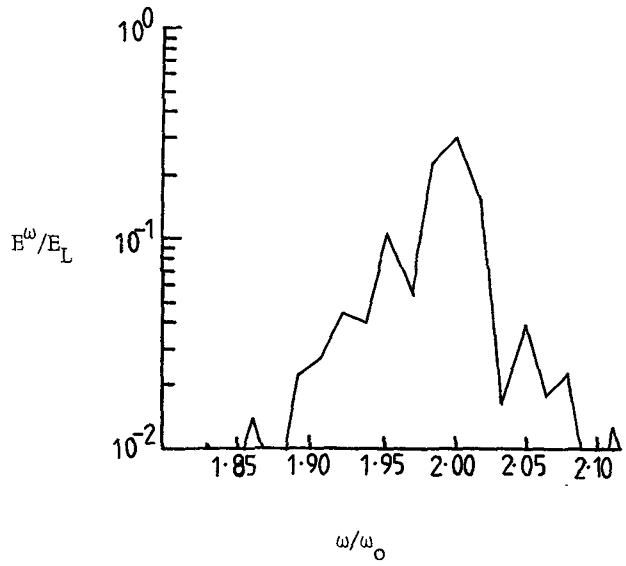


The dominant component of the resonantly induced current density lies across the density gradient, i.e. along Oy . This component is responsible for inducing a magnetic field along Oz . This field is quasi-static and, in the cold plasma limit, is restricted spatially to the plasma resonant region. However warm plasma theory predicts that the magnetic field will extend into the over-dense region, and this is observed in the computer simulations. Fig. 2 shows a plot, from our simulations, of the time-averaged magnetic field. The direction of the field reverses inside the resonant region which extends over 2Δ . Also the field extends into the over-dense plasma.

We have also examined the influence of the magnetic field effects on the harmonic line profiles. Fig. 3, taken from a run of our 1½-D fully electromagnetic code shows the line structure present on the second harmonic emission spectrum. The frequency shift of the first side band, relative to the line centre, can be seen. This is strongly dependent on magnetic field intensity.

In summary we have shown that significant harmonic emission may be produced in laser produced plasmas with strong magnetic fields. The harmonics show structure consistent with the excitation of Bernstein modes. The simulations also indicate that strong quasi-static magnetic fields are generated in the neighbourhood of the critical density.

Fig. 3



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