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Centre de Recherches en Physique des Plasmas
Association Euratom - Confédération Suisse
Ecole Polytechnique Fédérale de Lausanne
21, av. des Bains, CH-1007 Lausanne/Switzerland

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ABSTRACT :

The amplitude of the magnetic broadband fluctuations in an ohmically heated tokamak is measured to have an inverse relationship with both the density and the electron confinement time.

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1. INTRODUCTION

Energy and particle transport in tokamaks are much faster than predicted from neoclassical theory. It is therefore reasonable to ask whether this anomalous transport is associated with the presence of plasma fluctuations [1-3]. Density fluctuations have received considerable attention in scattering experiments [4-8] and a relationship between local density fluctuations and anomalous thermal transport was established by TFR [8]. Magnetic fluctuations [9,10] may also play an important role in anomalous electron heat conduction, and preliminary studies have been made in relation to the confinement time in neutral beam heated discharges [11,12]. In this letter we present measurements of magnetic fluctuations in the ohmic regime, made with probes located in the scrape-off layer, which show a strong correlation between the level of fluctuations, the line-averaged density and also with the confinement time.

The main TCA parameters are $R/a = (0.61\text{m}/0.18\text{m}) = 3.4$, $B_\phi < 1.5$ T and $I_p \leqslant 175$ kA [13], with discharges reaching q=2 and $\bar{n}R/B_\phi \approx 4.4\times10^{19}$ Wb^{-1} without any gettering and with carbon limiters. Large bandwidth magnetic probes, measuring the 3 components $\tilde{b}_r$, $\tilde{b}_\theta$, $\tilde{b}_\phi$ of the magnetic wavefield, are placed behind the limiters in ceramic tubes. The different frequency components of the signal are electronically separated, so as to provide information about the Mirnov oscillations (~10 kHz) and the broadband turbulence spectrum (BTS), at frequencies up to ~1 MHz. Electrostatic pick-up has been shown to be negligible. The measurements are based on two triple probes, one placed on the equator at the low-field side, and the other placed on top of the plasma.

2. EXPERIMENTAL RESULTS

We shall describe in this paper the magnetic broadband turbulence spectrum observed during ohmic heating. The BTS extends typically from 50 kHz to ~1 MHz and shows no particular structure contrary to the coherent structure of Mirnov oscillations at 10 kHz. The amplitude decreases monotonically as a function of frequency, following a f^{-2} dependence on the $\tilde{b}_r$ and $\tilde{b}_\theta$ components as shown in Fig. 1; $\tilde{b}_\phi$

shows a slightly steeper dependence. The levels of measured amplitude are similar on $\tilde{b}_r$ and $\tilde{b}_\theta$, and smaller by a factor 3 for $\tilde{b}_\phi$, showing a strong anisotropy with respect to the main magnetic field.

In the following and for the sake of simplicity, the results shown have been restricted to the equatorial b_θ probe and to a window around 150 kHz with a 10 kHz bandwidth Δf, which does not restrict the generality of the following results. This particular frequency gives an adequate level of signal over a broad experimental range. At 150 kHz, the level of magnetic fluctuation $\tilde{b}_\theta/B_T\sqrt{\Delta f}$ is typically in the range below 10^{-6}. The measured magnetic turbulence amplitude depends rather weakly on the spacing between the plasma and the probe, shown by displacing the plasma by additional vertical field. At 100 kHz, the signal diminishes only by a factor 2 with a 5 cm imposed additional spacing (normal spacing : 5 cm).

As the density is increased by gas-puffing, the amplitude of magnetic turbulence is observed to decrease over the whole range of frequencies. This correlation between density and the turbulence level at 150 kHz is shown during a single discharge in Fig. 2. Other shot parameters are also presented. The correlation at a number of points in time is shown in Fig. 3. The data have been taken from the parameter range B_ϕ=1.5 T, q=3.2, and line-averaged densities between 1.2 and 5.0×10^{19} m^{-3}, for more than 40 discharges. Several time points have been chosen in each discharge during the current flat-top, with a slowly-varying density. All shots have sawtooth activity and no run-away population is distinguishable according to the hard X-ray signals. The inverse relation between BTS amplitude and density is clearly shown.

It is interesting to note that such a dependence was conjectured by Cook et al. [14] with $<(\tilde{b}/B_T)^2>$ varying as $(1/\bar{n}_e)^2$. Our results seem to show an even stronger dependence.

Analysis of the data used in this scan reveals that the electron energy confinement time τ_{E_e}, is proportional to line-averaged density, as in "Alcator" scaling. This is shown in Fig. 4 where the same data points have been plotted against the density. The confinement time $\tau_{E_e} \cong 0.28 \mathrm{x} n_{e_{19}} T_{ex}(0)(\mathrm{eV})/P_{OH}$ is obtained by using a central chord soft X-ray temperature and a central chord 2 mm interferometer density. This τ_{E_e} should be a good indication of the global confinement time, especially with constant plasma current, where the temperature profile should not vary greatly, and with quasi-stationary density. The density radial profile was measured to be roughly parabolic using an 8-channel interferometer, the electron temperature was assumed to be a parabola cubed, in agreement with Thomson scattering measurements. The solid line in Fig. 4 is a prediction of an Alcator type scaling [15] which fits the TCA experimental electron confinement times. The generally observed saturation of τ_{E_e} with density because of the increased loss due to ion neoclassical thermal conductivity is not apparent in this low density range. The saturation is actually predicted to occur at about $\bar{n}=5 \mathrm{x} 10^{19}$ m^{-3} (where $\tau_{E_e}{}^{EXP} = \tau_{E_i}{}^{NC}$). The data for this scan fall therefore in the electron-loss dominated, "Alcator" regime.

For the reasons mentioned above, the confinement time and the density should show the same inverse relationship with BTS amplitude. This is clearly seen in Fig. 5. It is interesting to note that the data scatter is reduced compared with that in Fig. 3.

3. CONCLUSION

The magnetic broadband turbulence spectrum, as measured by external magnetic probes, has been characterized for the different spatial directions. A strong correlation has been observed in ohmic discharges between the level of magnetic turbulence and both the density and the confinement time. As the density is increased, the confinement time increases and the fluctuation levels decrease, suggesting that magnetic turbulent activity may be related to energy loss. The spatial origin of the fluctuations cannot be determined with the present experiment. It may, however, be noted that the measured frequency dependence of the fluctuation spectrum is typical of measurements performed in the bulk plasma [10]. Of more relevance in this context is the fact that in this frequency range, magnetic activity is not localized on a magnetic surface, but the associated waves propagate radially. The measured fluctuations are thus not just localsurface phenomena, but can be generated by magnetic activity occuring in the bulk plasma, and can therefore be expected to reflect global performance.

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REFERENCES

[1] A.B. Rechester and M.N. Rosenbluth, Phys. Rev. Lett. 40 (1978) 38

[2] C. Chu, Phys. Rev. Lett. 48 (1982) 246

[3] F.A. Haas and A. Thyagaraja, Plasma Phys. 26 (1984) 641

[4] E. Mazzucato, Phys. Rev. Lett. 36 (1976) 792

[5] S.M. Hamberger et al., Phys. Rev. Lett. 37 (1976) 1345

[6] E. Mazzucato, Phys. Rev. Lett. 48 (1982) 1828

[7] C.M. Surko and R.E. Slusher, Science 221 (1983) 817 and references therein

[8] Equipe TFR, Plasma Phys. 25 (1983) 641

[9] S.J. Zweben, C.R. Menyuk, R.J. Taylor, Phys. Rev. Lett. 42 (1979) 1270

[10] S.J. Zweben, R.J. Taylor, Nucl. Fus. 21 (1981) 193

[11] B.A. Carreras et al., Oak Ridge Report, ORNL/T-8648 (1983) and B.A. Carreras et al., Phys. Rev. Lett. 50 (1983) 503

[12] E.J. Strait et al., Proc. 11th EPS Conf. on Contr. Fus. and Plasma Phys., Aachen, vol. I, A09 (1983) 59

[13] A.D. Cheetham et al., Proc. 11th SOFT, Oxford, vol. I (1980) 601; Lausanne Report LRP 162/80

[14] I. Cook, F.A. Haas and A. Thyagaraja, Plasma Phys. 24 (1982) 331

[15] Equipe TFR, Nucl. Fus. 20 (1980) 1227

Figure Captions

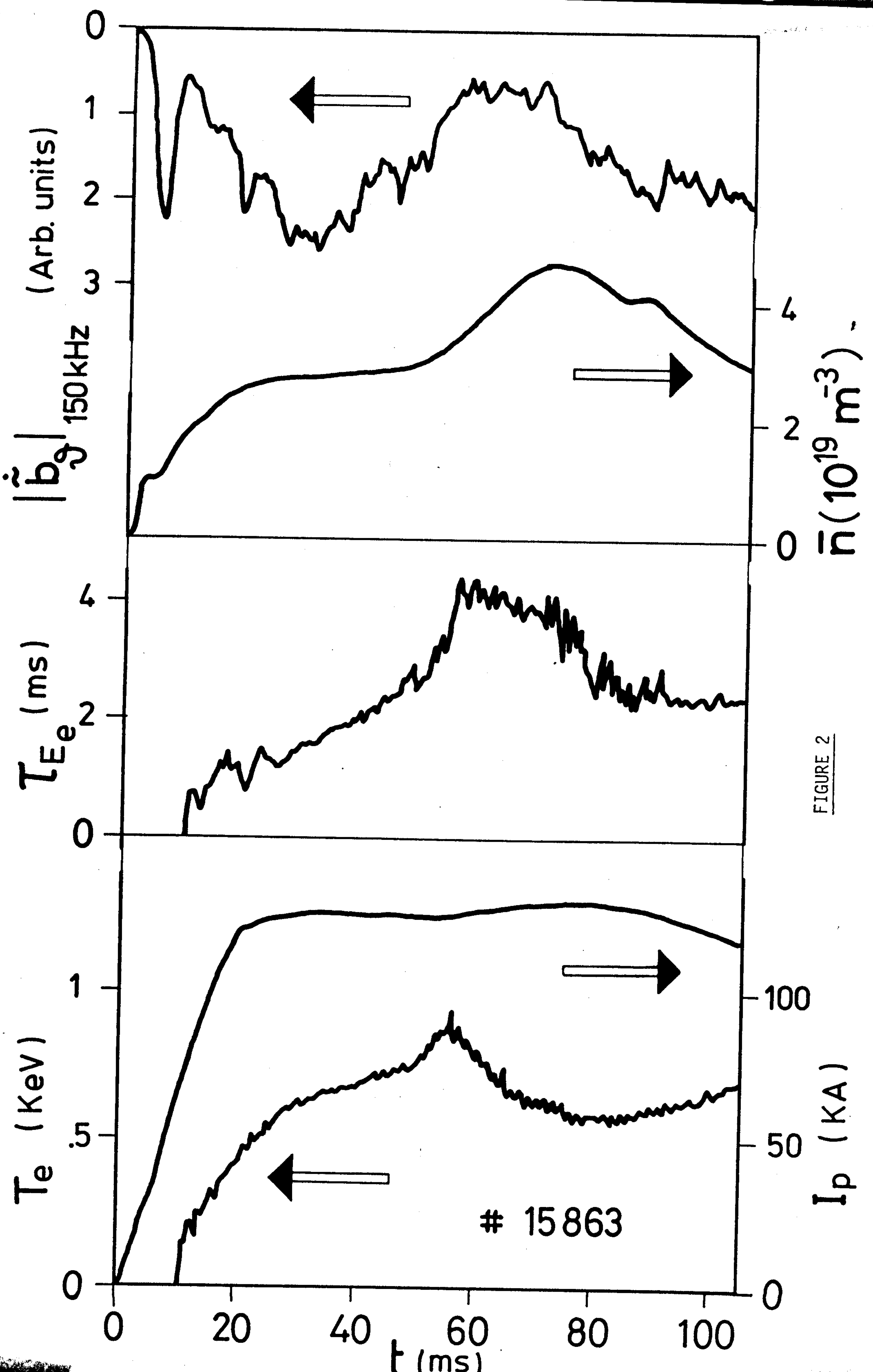
Fig. 1 : Magnetic broadband turbulence spectrum $|\dot{\tilde{b}}|^2$.

Fig. 2 : Magnetic turbulence at 150 KHz and other discharge parameters. D_2, B_ϕ=1.5 T.

Fig. 3 : Density versus magnetic turbulence.

Fig. 4 : The electron-conduction dominated Alcator scaling of energy confinement time.

Fig. 5 : Electron energy confinement time versus magnetic turbulence.



$|\tilde{\dot{b}}_\vartheta|_{150\,kHz}$ (Arb. units)
0
1
2
3
$\bar{n}(10^{19}\,m^{-3})$
0
2
4
τ_{E_e} (ms)
0
2
4
T_e (KeV)
0
.5
1
I_p (KA)
0
50
100
15 863
t (ms)
0
20
40
60
80
100

FIGURE 2

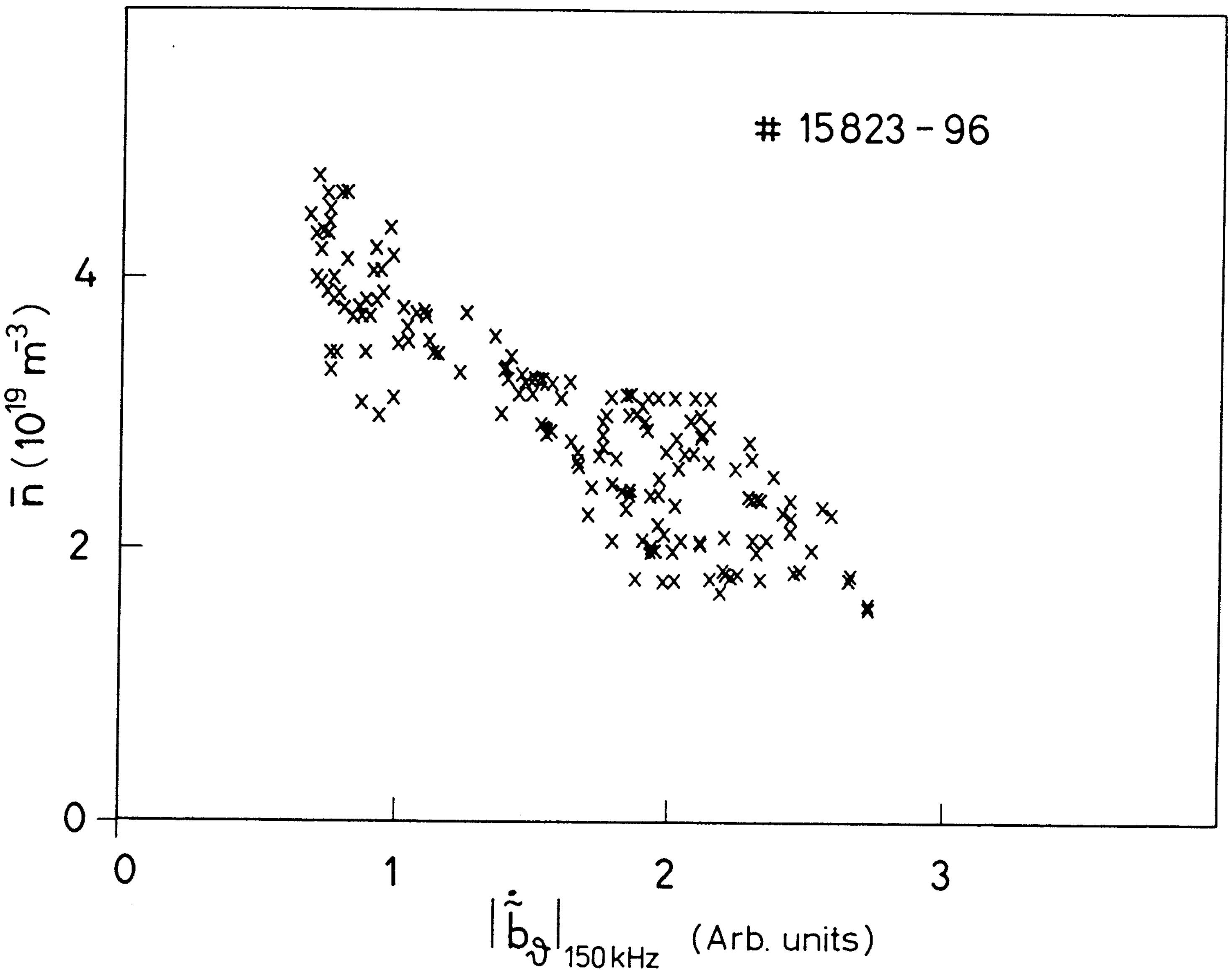

15823 - 96
$\bar{n}$ (10^{19} m^{-3})
0
2
4
0
1
2
3
$|\tilde{b}_\vartheta|_{150\,kHz}$ (Arb. units)

FIGURE 3

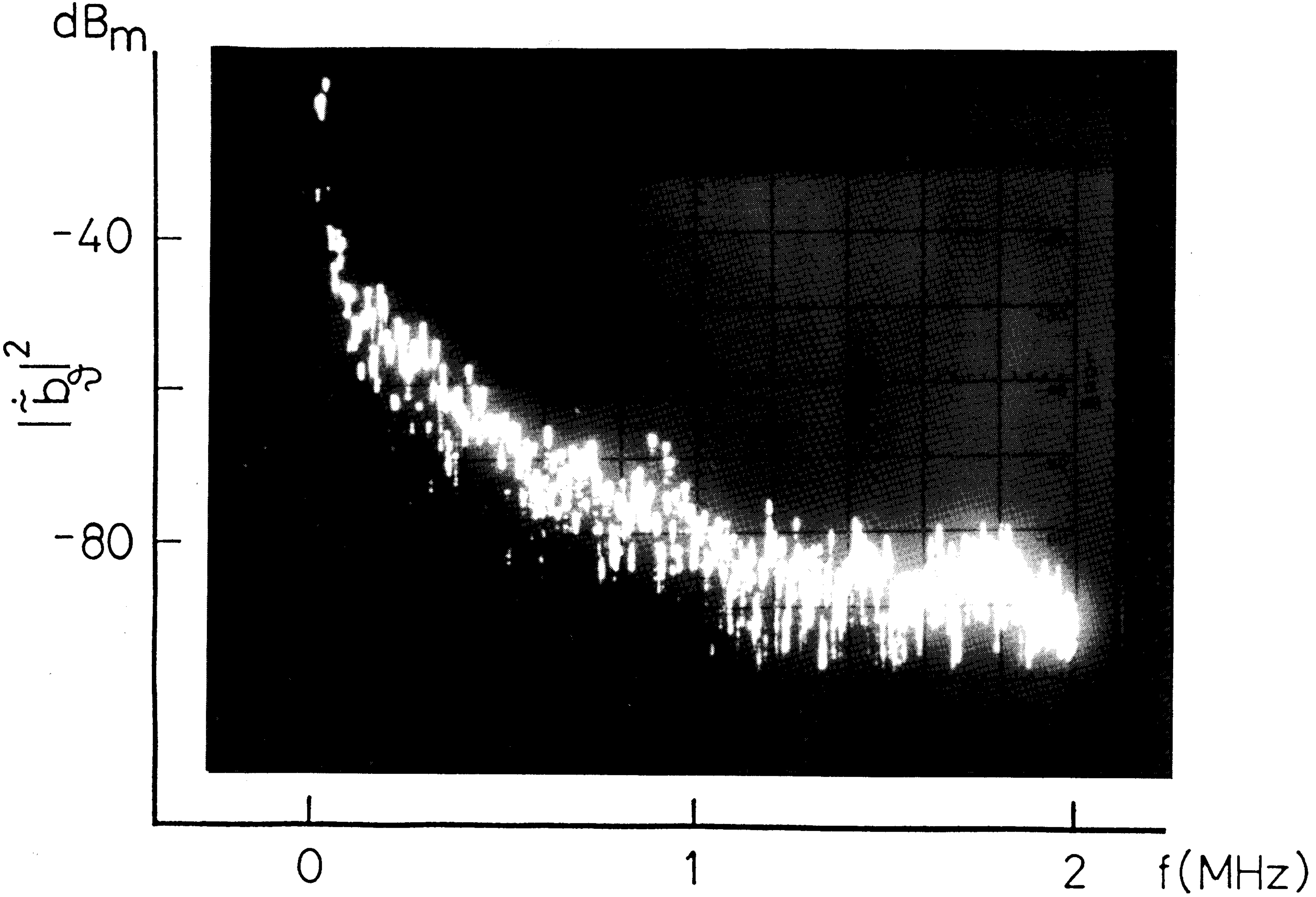
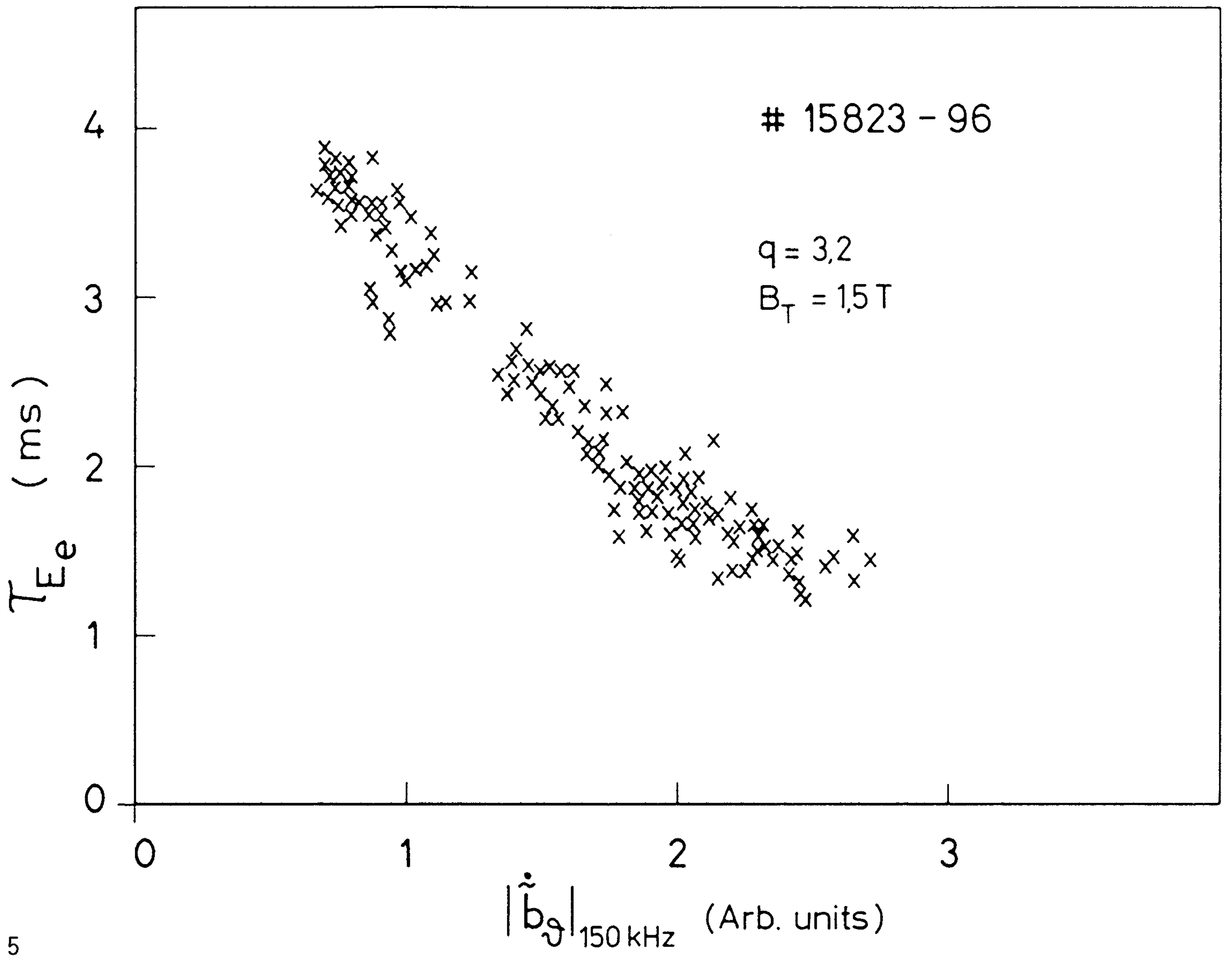


FIGURE 1



# 15823 - 96
q = 3,2
B_T = 1,5 T
τ_{E_e} (ms)
0
1
2
3
4
0
1
2
3
$|\dot{\tilde{b}}_\vartheta|_{150\,\mathrm{kHz}}$ (Arb. units)

FIGURE 5

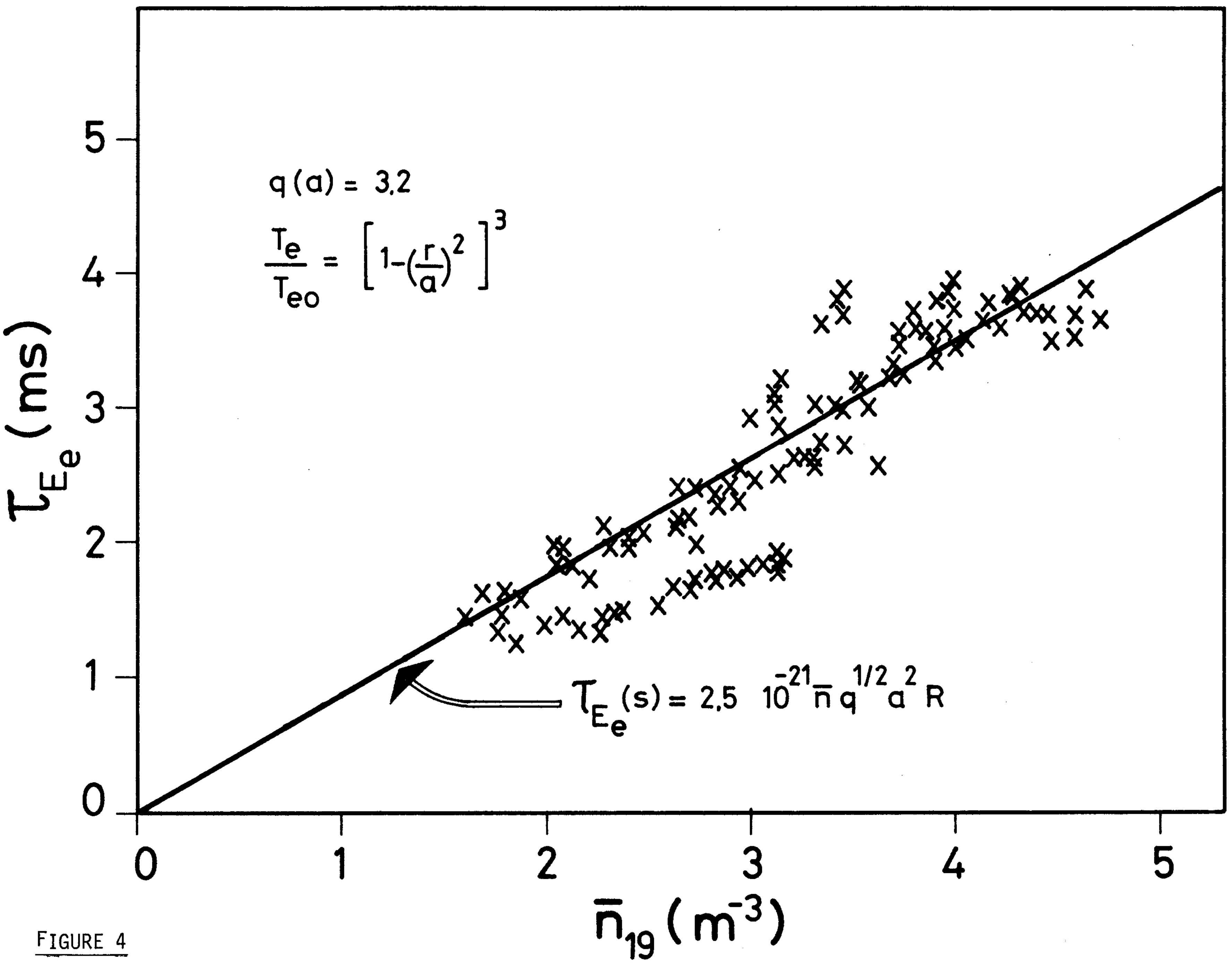

τ_{E_e} (ms)
5
4
3
2
1
0
$\bar{n}_{19}$ (m^{-3})
0
1
2
3
4
5
q (a) = 3,2
$\frac{T_e}{T_{eo}} = \left[1-\left(\frac{r}{a}\right)^2\right]^3$
$\tau_{E_e}(s) = 2{,}5 \quad 10^{-21}\,\bar{n}\,q^{1/2}\,a^2\,R$

FIGURE 4