

## Electron Acceleration Near ICRF Antennas

V. Petržílka<sup>1</sup>, V. Fuchs<sup>1</sup>, L. Krlín<sup>1</sup>, L. Colas<sup>2</sup>, M. Goniche<sup>2</sup>, S. Heuraux<sup>3</sup>, V. Bobkov<sup>4</sup>,  
F. Braun<sup>4</sup>, R. Dux<sup>4</sup>, R. Neu<sup>4</sup>, J.M. Noterdaeme<sup>4,5</sup>

<sup>1</sup>Association Euratom/IPP.CR, Prague, Czech Republic

<sup>2</sup>Association Euratom/CEA Cadarache, France, <sup>3</sup>LPMI, Université Nancy, France

<sup>4</sup>Association Euratom/IPP Garching, Germany, <sup>5</sup>EESA Dep., University Gent, Belgium

### 1. Introduction

It is demonstrated that thermal electrons can be accelerated to energy of several keV, when moving along magnetostatic field B lines near an ICRF (Ion Cyclotron Resonance Frequency) antenna. The electron can gain energy in passing the near antenna rf field inhomogeneity, because of the temporal phase changes of the field which do not average out on the electron quiver motion time scale. This process is similar to electron acceleration in front of lower hybrid wave antennas [1], when the electron passes in front of the septum between wave-guides. The electron energy rises by repeated passes through the near antenna rf field inhomogeneity, as the electrons are reflected at the sheath on ICRF antenna components, such as parts of the antenna box and antenna guard limiters, until the electron kinetic energy reaches or overcomes the sheath potential. In turn, the sheath potential corresponding to the rectified rf potential can be enhanced by those energetic electrons [2], whose kinetic energy is larger than the sheath potential and which hit the antenna parts, if the electron flux becomes greater than the local Bohm's flux. The increased sheath potential can cause stronger ion acceleration and plasma convection near the ICRF antennas [3]. This novel acceleration process can thus participate in creation of high thermal loads (hot spots) observed on antennas. For the numerical modeling, the rf field was computed with the ICANT code [4] for 1 MW launched in monopole and dipole phasings by a Tore Supra antenna, or with the HFSS code (ANSOFT®) for 1 MW launched in dipole phasing by an ASDEX Upgrade antenna. We use test particle computations to estimate the energy gain of electrons as a function of time and as a function of the RF electric field intensity.

### 2. Electron Acceleration

An ensemble of 300 test electrons with a thermal Maxwellian velocity distribution at 30 eV is injected at equal distances along the line (which is parallel to B), Fig. 1. The motion

along this line illustrates the case of electrons accelerated when going through regions of maximum oscillating fields in the antenna vicinity, just in front of the Faraday screen.

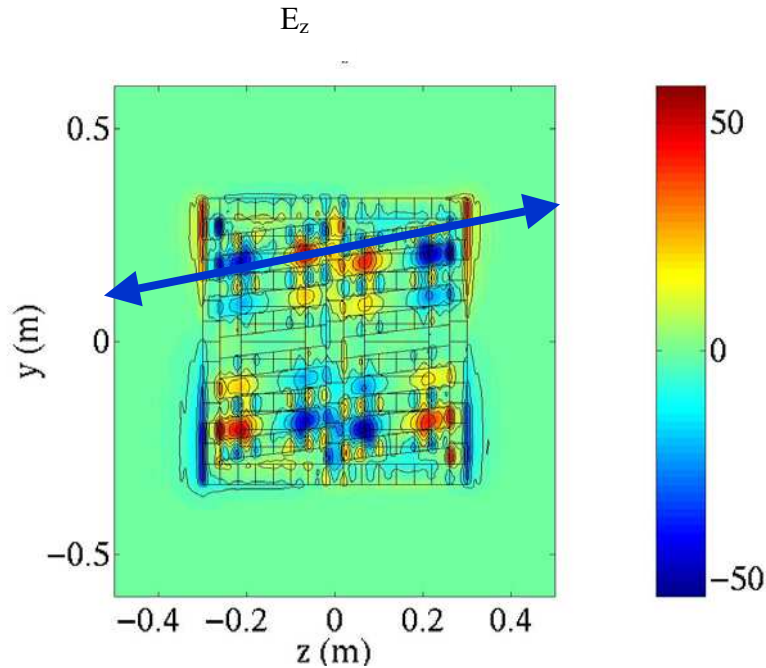


Fig. 1.  $E_z$  (kV/m) field of the Tore Supra antenna, still in vacuum and just in front of the Faraday screen, the rf frequency is 48 MHz, the boundary plasma density  $8 \times 10^{18} \text{ m}^{-3}$ .

At first, it is assumed that the electrons are always reflected by the sheath potential  $U$  at the end of the arrows at the blue line, at  $z = -0.5$  and  $0.5$ , where the guard limiters are located. In other words, we at first assume that  $U$  is larger than the electron kinetic energy. The motion of the test electrons is followed in time. Fig. 2a shows the ensemble averaged total electron energy  $W_T$ . The electron energy in Fig. 2a grows, but it eventually saturates as a function of time. This growth is due to velocity space diffusion of electrons in the resonant part of the ICRF spectrum experienced by electrons bouncing between the sheaths. This is similar to the electron acceleration mechanism at a lower hybrid antenna [1]. As the energy of electrons is growing, the assumption of total reflection at the sheaths is necessarily violated. However, the electron energy and the sheath voltage grow together. This process will need to be investigated as the next step. After some time interval, the sheath voltage should reach a new equilibrium value. When the new value of the sheath voltage will be determined, its consequences for the edge plasma convection may be estimated, similarly as it was done in [3]. In the calculations represented in Fig. 2b, we dropped the assumption that all electrons are reflected at the sheath. Fig. 2b then

gives the number of electrons, which are *not reflected* by a finite sheath potential  $U$ , after a certain acceleration time along the blue line.

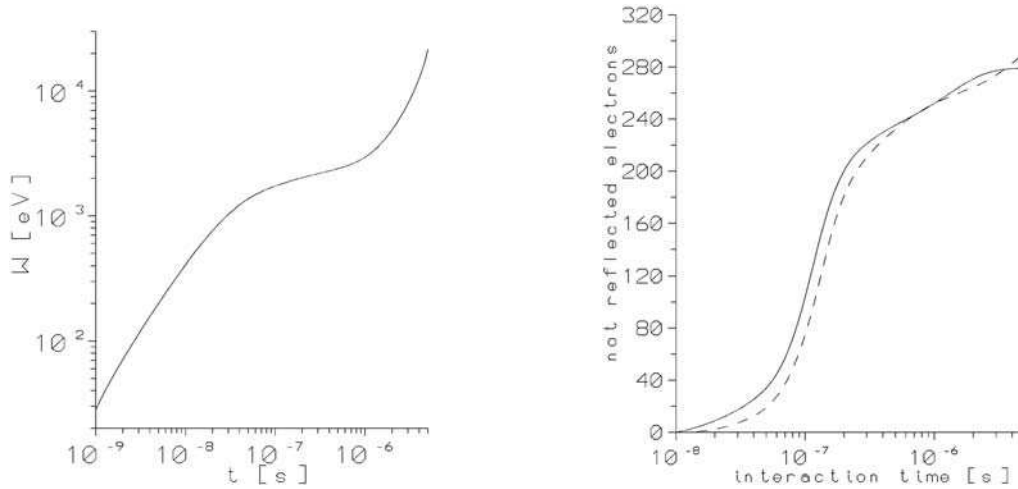


Fig. 2: a) The total energy gain  $W_T$  along the blue line as a function of time. It is assumed that electrons are reflected at the ends of the blue line. b) The number of the electrons out of the total number of 300 injected electrons, which are not reflected (because their energy is larger than  $U$ ) at the ends of the blue line. Solid line: The sheath potential  $U = 3Te + (Urf/2)(1 + \cos(\omega t))$ ; dashed line:  $U = 3Te + Urf$ ;  $Urf = 1500$  V.

Figure 3 then gives the scan along the poloidal coordinate  $y$  of the electron acceleration in front of the ICRF antenna for dipole and monopole Tore Supra antenna phasings. Here it is again assumed, as in Fig. 2a, that the electrons are always reflected by the sheet.

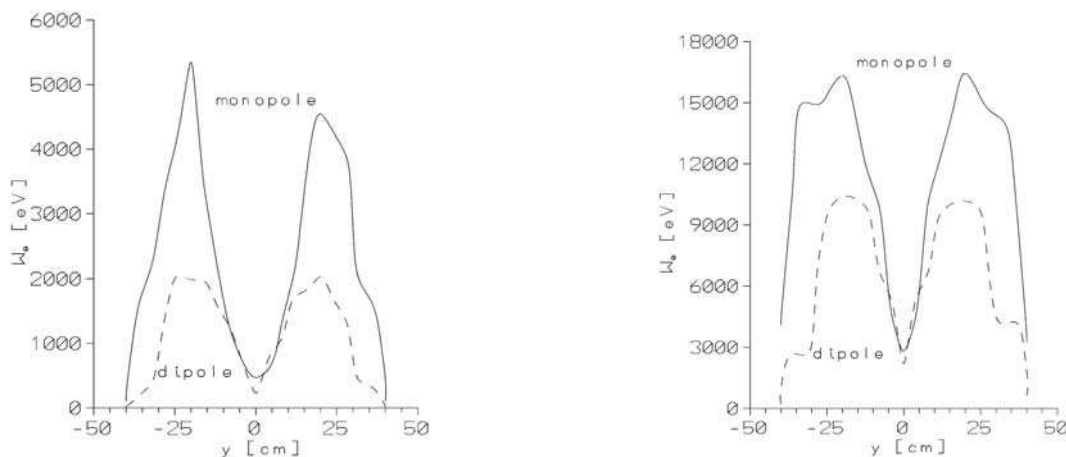


Fig. 3. Left: Ensemble averaged final energy of 300 thermal test electrons. Right: Maximum electron energy, which was acquired by the most accelerated electron. The peaks of the curves correspond to the poloidal peaks of the electric field amplitude, cf. Fig. 1. The electrons bounce between guard limiters at  $z = -50$  and  $50$  cm.

The electron path was followed for two microseconds over 40 poloidally (coordinate  $y$ ) equidistant lines along  $B$  with tilt 7 degrees. The radial plane, in which the fields are computed, is 1 cm in front of the box; the current straps are recessed minus 2.5 cm into the box; this means that the particle moves 3.5 cm in front of the straps; plasma is 5.5 cm in front of the straps, i.e. plasma is 2 cm in front of the plane, where the particle moves, and 3 cm from the box boundaries. It can be seen that the maximum electron acceleration takes place at the line passing through the poloidal maximum of the electric field amplitude. Finally, we complement the preceding modeling of electron acceleration by the Tore Supra ICRF antenna by results, shown in the table below, of calculations of electron acceleration along three magnetostatic (tilt 7 deg - the Faraday screen has a tilt of 15 deg) field lines of an ASDEX Upgrade ICRF antenna. The lines were chosen in order to intersect three locations poloidally in the center and in the upper and lower halves of the antenna, where spectroscopic observations of the antenna guard limiter are made. Traces of the energetic electron beam might possibly be observed there as bright spots:

	vacuum	water load
upper line	288 eV	1718 eV
center line	1443 eV	303 eV
lower line	282 eV	1066 eV

The fields were calculated in two cases: (i) the antenna radiates into vacuum, (ii) the antenna load is modeled by water in the field calculations. The sheath potential was chosen as  $U=3Te+(Urf/2)(1+\cos(\omega t))$ , like in Fig. 2b. It can be seen that the load significantly changes the acceleration pattern: Without the load, the acceleration is most strong at the central line, but with the load, the opposite is true. In conclusion, a novel process of electron acceleration near the ICRF antenna, the physics of which is similar to the well known electron acceleration process in front of the LH grills [1], was identified and explored. It was shown that the novel acceleration mechanism can produce energetic electrons near ICRF antennas, which then can produce hot spots directly, or indirectly by enhancing the sheath potential and in turn the ion acceleration in the sheath.

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