ANALYSIS OF TRAVELLING FAST WAVE ICRF ANTENNA RADIATING FROM A RECESS IN FIRST TOKAMAK WALL

V.L. Vdovin

Russian Research Centre "Kurchatov Institute", Institute of Nuclear Fusion, Moscow

We propose new type frequency broad band travelling wave ICRF antenna for a Fast Wave (FW) Current Drive (CD) and heating in large scale tokamak plasmas. Antenna consists of toroidal array of poloidal loops supported by ridge waveguide. The last one is necessary to provide needed antenna dispersion properties and broad frequency band to cover with a single antenna as FW CD and heating scenarios. Antenna is located in a special recess of first tokamak wall and does not make use the lumped capacitances.

We develop the theory of such an antenna by matching the EM fields at the ridge waveguide, the toroidal antenna slots (located between neighbour poloidal loops) at the first tokamak wall and a plasma surface. The poloidal antenna RF spectrum is treated self consistently in compare with previous investigations [1,2]. The dispersion relation to find the antenna's toroidal propagation constant/slow down (i.e. Flocke multiplier) and its dependences over frequency, antenna geometry (period, ridge and loop sizes), divertor thickness and plasma parameters are discussed.

1. Qualitative analysis of new type antenna

The geometry of new type ICRF TW antenna proposed on Fig.1 (similar antenna was proposed by us to the ITER [3] earlier). It consists of toroidal array of short-circuited poloidal conductors (loops with period T) installed in the first tokamak wall recess of height L. This array we initially treat as a multi-conductor transmission line which can carry EM waves with toroidal propagation constant β, so βT is being a phase shift of poloidal RF currents of two neighbouring loops ($< \pi$). These loops are resonating at $L = \lambda/2$ (λ - free space wave length). There is, of course second higher frequency band, interesting for ITER. Now important step is to push in the middle part of the back wall of the recess toward to the loops (square step of the height b and wide L - 2h on Fig.1), creating the ridge waveguide structure. The EM fields decay from the loops in radial direction with an exponent β: for ex., $E_y \sim \exp(-\beta x)$ (x axis direction on Fig.1). When the propagation constant is large one this field does not touch the ridge waveguide. With smaller β values the fields start to touch the ridge , they are pushed out to the “leg” regions of the ridge waveguide. Relatively, the frequency is decreased. So crudely we can evaluate the lower frequency of TWA proposed as a lowest cut off frequency of our ridge waveguide (because at the cut off there are no toroidal currents in the waveguide and the poloidal cuts between loops of the array are not important ones).

2. Basic equations and fields matching

In region (1) electrical and magnetic wave fields (z - along magnetic field B_o) are given:

$$E_z^{(1)} = \sum_{r,n} \left(A_{rn} e^{i\chi_{rn} x} + B_{rn} e^{-i\chi_{rn} x} \right) \sin(k_r y) \cdot e^{i\bar{k}_n z} \qquad (1.1)$$

$$B_z^{(1)} = \sum_{rn} \left(a_{rn} e^{i\chi_{rn} x} + b_{rn} e^{-i\chi_{rn} x} \right) \sin(k_r y) \cdot e^{i\bar{k}_n z} \qquad (1.2)$$

where

$\chi_{rn}^2 = k_0^2 - \bar{k}_n^2 - k_r^2$, $\bar{k}_n = k_n + \beta$, $k_n = 2\pi \frac{n}{T}$, $k_r = \pi \frac{r}{L}$, n = 0,±1,±2,., r = 1, 3, 5, …

In region II (wells) are valid the same formulas with change k_n to $k_m=\pi m/h$, m=0,±1,±2,…

$\bar{\chi}_{mn}^2 = k_0^2 - \bar{k}_n^2 - \left(\pi \frac{m}{h} \right)^2$. Matching of poloidal fields at wells mouths $E_y^{(1)} = E_y^{(2)}|_{x=0}$ is:

$$i\chi_{m'n} \left(a_{m'n} - b_{m'n} \right) \frac{L}{4} = \sum_m i\bar{\chi}_{mn} \left(a'_{mn} - b'_{mn} \right) K_{m'm} \frac{h}{4} \qquad (2)$$

$$K_{m'm} = \frac{4}{h} \int_0^{h/2} \cos(k_{m'} y) \cos(k'_{m} y) dy \qquad (3)$$

The component B_z we match only at the mouth of the well. We multiply $B_z^{(2)}$ by $\cos(k_m y)$ and integrate from 0 to h/2:

$$\theta_m \left(a'_{mn} + b'_{mn} \right) \frac{h}{2} = \frac{L}{4} \sum_r \left(a_{rn} + b_{rn} \right) K_{rm} \qquad (4)$$

Also $b'_{mn} = a'_{mn} \exp\left(-2i\bar{\chi}_{mn} b \right)$ due to $\partial B_z / \partial x|_{x=-b} = 0$. Here $\theta_m = 2$, m = 0 and $\theta_m=1$, m ≠ 0. From (2) and (4) we obtain:

$$a_{m'n} - b_{m'n} = \frac{h}{L} \frac{1}{\chi_{m'n}} \sum_r \left(a_{rn} + b_{rn} \right) \Theta_{rm'}^{(n)} \qquad (5)$$

where

$$\Theta_{rm'}^{(n)} = -\sum_m \frac{\bar{\chi}_{mn} th| \bar{\chi}_{mn} b|}{\theta_m} K_{rm} K_{m'm}$$

Now we equate $B_z^{(3)}|_{x=+a} = B_z^{(2)}|_{x=-a}$ in a space between neighbouring poloidal loops, multiply both sides by $\exp(-i\bar{k}_n z)$ and integrate from Z_p - *l* to Z_p + *l* (Z_p = pT, p - number of poloidal conductor). Each poloidal harmonic $\cos(\pi \nu y/L)$ can be treated separately and one obtains:

$$\sum_n \left(a_{\nu n} e^{i\chi_{\nu n} a} + b_{\nu n} e^{-i\chi_{\nu n} a}\right) D_{nn'} = \sum_n \left(c_{\nu n} e^{i\chi_{\nu n} a} + d_{\nu n} e^{-i\chi_{\nu n} a}\right) D_{nn'} \qquad (6)$$

$$D_{nn'} = \frac{\sin\left(k_n - k_{n'}\right) l}{k_n - k_{n'}} \ , \ \ k_n = \pi \frac{n}{L} \qquad (6.1)$$

The poloidal electric field E_y is continuous over the full slow down structure period T and the integration of $\partial B_z / \partial x|_{x=a}$ over z from Z_p to $Z_p + T$ gives additional equation.

In following we assume Fast Waves (FW) radiation into half space homogeneous plasma with famous perpendicular wave number $k_\perp$. Matching fields at plasma surface gives us final equation:

$$\sum_n \left\{a_{\nu n}\left(1 - M_{\nu n}\right) e^{i\chi_{\nu n} a} + b_{\nu n}\left(1 + M_{\nu n}\right) e^{-i\chi_{\nu n} a}\right\} D_{nn} = 0 \qquad (7)$$

$$M_{\nu n} = \frac{1 - \gamma_{\nu n} e^{1i\chi_{\nu n}(c-a)}}{1 + \gamma_{\nu n} e^{2i\chi_{\nu n}(c-a)}} \ , \ \gamma_{\nu n} = \frac{k_{\perp,\nu n} - \chi_{\nu n}}{k_{\perp,\nu n} + \chi_{\nu n}} \ , \ k^2_{\perp,\nu n} = k^2_{\perp,\nu} - k^2_{y,\nu} \ , \ \nu = 1, 3, 5, \ldots$$

To complete our procedure we rewrite Eq.(12) to more convenient form (δ_{ij} - Kronecker symbol):

$$\sum_r \left\{\left(\frac{h}{L}\frac{1}{\chi_{m'n}} \Theta^{(n)}_{rm'} a_{rn} - \delta_{rm'} a_{m'n}\right) + \left(\frac{h}{L}\frac{1}{\chi_{m'n}} \Theta^{(n)}_{rm'} b_{rn} + \delta_{rm'} b_{m'n}\right)\right\} = 0 \qquad (8)$$

3. Conclusions

We have obtained the dispersion relation for slow wave, which yields main TW antenna characteristic - antenna toroidal propagation constant β - equating the determinant to Eqs.(7) and (8) to zero. The key problem now is to investigate beta dependence over a generator frequency (main and easy controller of TWA slow down), antenna geometry and plasma parameters. Another important TW antenna characteristic is its wave impedance Z. When slow down beta is found it is possible to find Z = R + iX, the active part R being responsible for TWA's coupling with a plasma. Because of the classic poloidal loop structure of the proposed ICRF antenna it is evident that R dependencies over antenna - plasma distances are similar to usual ICRF loop antennae (see also [2]).

References

[1] Moeller C.P. et al.: *Eur. Topical RF conference*, Brussels 1992

[2] Vdovin V.L.: *Eur. Conf. on Plasma Physics and Contr. Fus.*, Lisboa 1993, v.**3**, p.127

[3] Vdovin V.L., Kamenskij I.V. et al.: "ICRF heating and Current Drive in ITER." Russian contribution, *ITER meeting on Heating and CD in ITER*, Garching 1993.

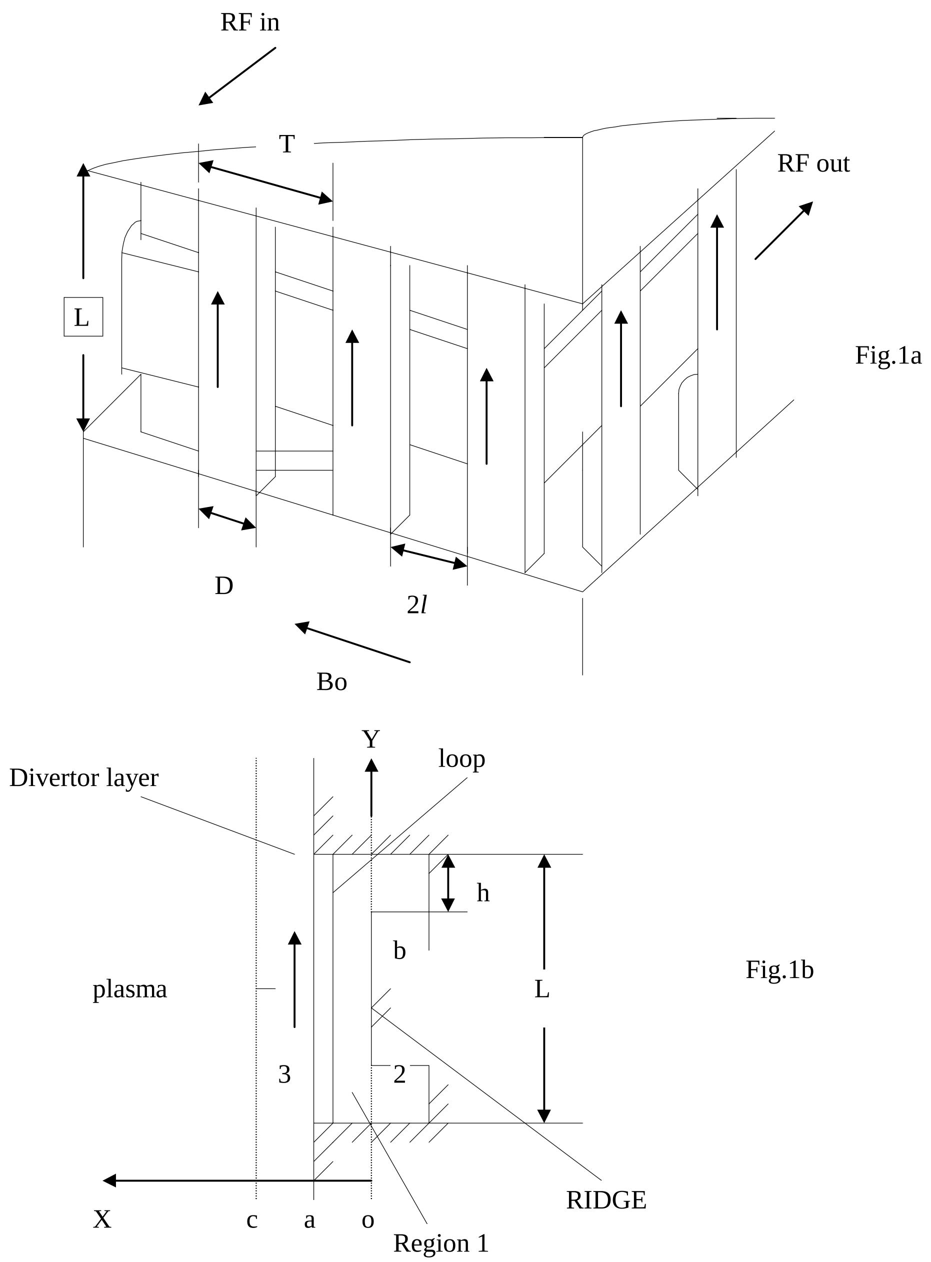

Fig. 1 . Travelling Wave antenna geometry (Fig.1a - bird view from a plasma centre, Fig.1b - poloidal antenna-plasma cross section)