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New developments in ICRH antennas on TEXTOR

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Introduction

The ICRH system installed on TEXTOR consists of two heating lines, each fed by a 2MW generator (in the frequency band 25-38MHz) and connected to an antenna pair which is usually operated in π phasing [1]. New developments on ICRH antennae are being performed to increase their voltage stand-off and to solve the problem of generator tripping with fast variation of plasma antenna loading. This in view to test solutions to increase the power capability and to decrease the sensitivity to ELM's of the ICRH system needed for ITER.

Low electric field ICRH antenna

On one of the two antenna pairs of TEXTOR the thin radiating strip has been replaced by a set of three cylinders (see on Fig.1 comparison between the cross-section of the thin (T) and the new low electric field antenna (LE)). This allows decreasing significantly the edge maximum electric field, on the sides of the strip, for a given radiated power. 2-D electrostatic modelling shows that for the same voltage V_A applied to the strip the maximum electric field appears at the edges and is reduced by a factor 1.6. Fig. 1 shows for the two cases the electric field distribution normalised each time to its maximum value. The effect of the plasma is approximated by a conducting plane in front of the strips. As the rf current density is larger at the inner side of the radiating strip [2] there is a loss of coupling to the plasma (expressed by its distributed loading resistance R_A) and a decrease of its distributed inductance L_A. As the radiated power $P = G_A |V_A|^2/2$ scales as $G_A \propto R_A/L_A^2$ there is partial compensation between the decrease of R_A and L_A on the input antenna conductance G_A ($G_{A,LE} = 70\ R_{A,LE}$ µS for the LE antenna and $G_{A,T} = 53\ R_{A,T}$ µS for the thin one). Fig.2 compares the evolution of R_A with the edge density for the two antennae in the same set of discharges. The ratio $R_{A,LE}/R_{A,T} \cong 0.68$ and for the same radiated power we have $V_{A,LE}/V_{A,T} \cong 1.06$. The LE antenna as the T antenna have been routinely operated with high reliability up to the full installed power (2MW on each from which 95% were radiated). If the power limitation is due to arcing between the strap and the antenna box one could expect an improvement in the power handling capability of the LE antenna by a factor $P_{LE}/P_T \cong 2.3$.

Load insensitive ICRH antenna

<u>*Set-up*</u>. Due to the rearrangement of the diagnostic positions resulting from the DED [3] installation on TEXTOR a new antenna system has been designed to be compatible with the inlet of the diagnostic beam of TEXTOR between its two radiating strips. This antenna has been designed to be able to test the "conjugated T "mode [4] of operation that is foreseen for the new JET-EP antenna [5]. This mode would be fairly insensitive to the variations of the

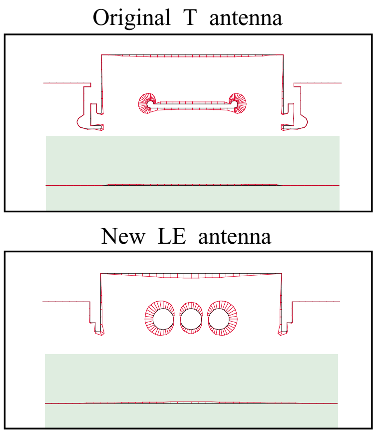

Fig.1 Cross-section of one antenna box of the "LE" and of the "L" antenna pairs with results of 2-D modelling.

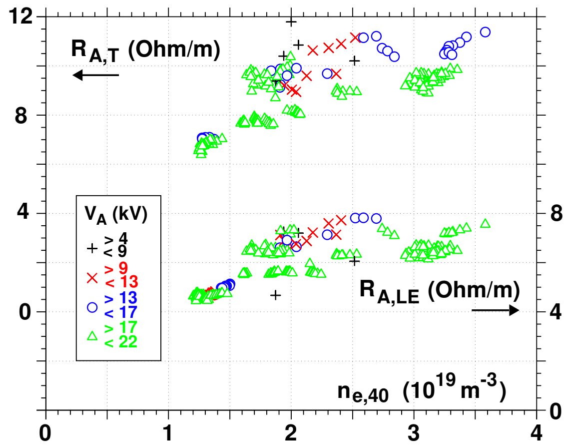

Fig.2 Distributed loading resistance R_A versus line averaged density near plasma edge (at 6cm of LCMS)

antenna loading resistance and could help solving the problem of generator tripping occurring in the ICRH heating of Elmy H-mode plasmas. A side and top view of the new antenna pair is shown respectively on Figs. 3a) and b). The two identical radiating straps (part A-C on Fig. 3a) are fed by their feeding lines at a tap B. They are short-circuited at one side and connected at the other side to a vacuum variable capacitor (grounded in E) by means of a section C-D of coaxial line. The two feeding lines are connected to the line coming from the generator by means of a T junction as shown schematically on Fig.3c). The lengths B_R-T and B_L-T between each tap and the "T" can be adjusted by means of the line stretchers $(LS)_R$ and $(LS)_L$.

<u>Modelling</u>. The antenna set-up of Fig.3c) is easily modelled by the transmission line theory: (i) the radiating strap by sections of lossy strip line characterised by the distributed resistance (due mainly to plasma loading) R_A, inductance L_A and capacitance C_A, (ii) the vacuum or pressurised air parts C-D and B-T by sections of coaxial lines of appropriate characteristic impedance, the capacitor C_p by its capacitance and stray inductance. The behaviour of this tunable system can be understood by means of a simplified equivalent circuit. For the frequency range used, the line path A-D has an electrical length shorter than a quarter wavelength $\lambda/4$ and behaves as an inductance L. The part A-E of the antenna system is equivalent to a parallel resonating circuit fed in B at the fraction α of this inductance as shown on Fig.4. We have $R \propto R_A$ ($R = R_A\, l_{A\text{-}C}$ in the limit of short electrical length $l_{A\text{-}D}$), L depends on L_A (L_A is a weak function of the plasma loading [1]) and C is determined by C_p and its stray inductance. The impedance seen in B is given by $Z_B = \alpha^2\,(L/(CR))\,(1\text{-}i2Q\Delta f/f)^{-1}$ with $\Delta f = f - f_{Cp}$, $f_{C\,p} = (LC_p)^{-1/2}$ and $Q = 2\pi\, f\, L\, /\, R$; f is the operating frequency. This expression is valid when Q is sufficiently large. At the position B' along the feeder which is at a distance $\lambda/4$ from the tap B the normalised impedance $z_{B'} = r + i\,x$ is given by $z_{B'} = Z_{B'}\,/\,Z_0 = Z_0\,/\,Z_B$ with $r = Z_0\, R\, C\, /\, (\alpha^2\, L)$ and $x = r2Q\Delta f/f$. These relations are valid for the right (subscript R) and the left straps (subscript L). We have also $z_{TR} = z_{B'R}$ and $z_{TL} = z_{B'L}$

when the electrical lengths $l_{B'R\text{-}T} = n\ \lambda/2$ and $l_{B'\ L\text{-}T} = m\ \lambda/2$ are equal to an integer number of half wavelengths.

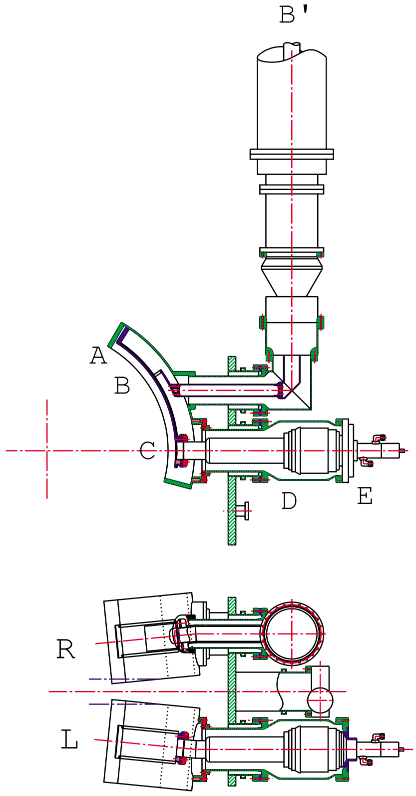

Fig.3 a), b) Side and top view of the tunable antenna pair. The top view shows on the R side the upper part and on the L side the lower part.

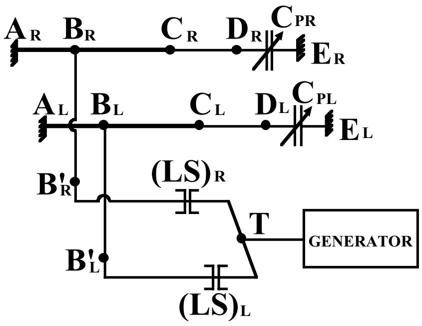

Fig.3c) Schematic diagram of the load insensitive antenna system

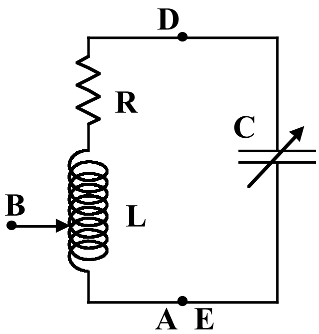

Fig.4 Equivalent circuit of the tunable strap.

The normalised admittance in T seen from the generator side is given by $y_T \equiv g + ib = y_{TR} + y_{TL}$ with $g=g_R + g_L$ and $b=b_R + b_L$. The same power is radiated by the two straps when $g_R = g_L$ (i). The generator sees a matched load when $y_T = 1$, i.e. when $b_R = -b_L$ (ii) and $g_R + g_L = 1$ (iii). If we choose C_{pR} and C_{pL} such that $z_{B'R} \cong z^*_{B'L}$,i.e. $x_R = -x_L \equiv x$, we satisfy the conditions (i) and (ii) and we have $y_T \cong g = (1/x)\ 2\zeta/(1+\zeta^2)$ with $\zeta = r / x$. If additionally $|x| \cong 1$ the matching is obtained for $|\zeta| = 1$ (condition (iii) satisfied). These matching conditions are fulfilled when $\zeta = 2Q\ \Delta f/f = \pm 1$ and $Z_0\ R\ C / (\alpha^2\ L) = 1$ and are approximately achieved by the right choice of C_{pR} and C_{pL} and of the tap position (i.e. value of α) for a reference $R = R_0 \propto R_{A0}$. In this case conditions close to matching will remain in a large R or R_A domain around R_0 or R_{A0} due to the stationarity of the function $2\zeta/(1+\zeta^2)$ around $\zeta = 1$. The VSWR remains below 1.5 for $0.38 < R_A / R_0 < 2.6$. This large independence of the matching on R_A has a drawback: The phase difference $\Delta\phi$ between the current in the two straps is depending on R_A through the relation $\Delta\phi \cong 2\ \mathrm{arctg}(1/x) + (m\text{-}n)\ \pi$.

Performances of the optimised " conjugated T"operation. The modelling of the complete set-up allows not only to optimise the values of C_{pR} , C_{pL} and α for the experimental range of R_A but also to further improve the performances by the adjustment of the lengths $l_{BR\text{-}T}$ near $n\ \lambda/2 + \lambda/4$ and $l_{BL\text{-}T}$ near $m\ \lambda/2 + \lambda/4$ by means of the line stretchers $(LS)_R$ and $(LS)_L$. The results of such a procedure are shown in Fig.5. A VSWR at the generator S lower than 1.1 can be maintained for an antenna loading resistance R_A varying between 2.5 and 9.5 Ohm/m and $S < 1.5$ for $1.6 < R_A < 16$ Ohm/m. Are also shown (i) that in the domain of low S , $y_{TR} \cong y^*_{TL}$and $g_R \cong g_L \cong 0.5$, (ii) the resulting power P_R and P_L radiated by each strap for a total input power P = 2 MW and (iii) the phase difference $\Delta\phi$ for m - n $\cong$ 1 (expressed in degrees).

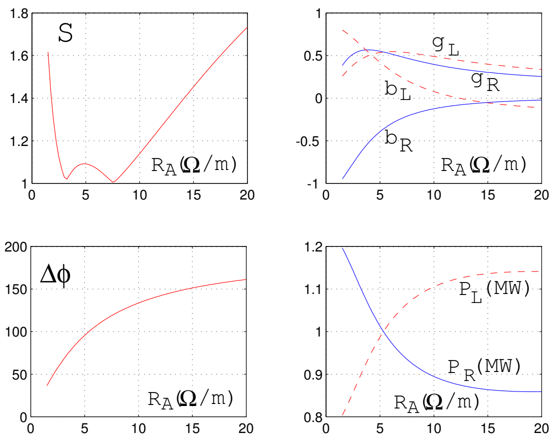

Fig.5 Performances of the optimised conjugated T operation (C_{pRv}= 80.4 pF, C_{pL} = 67.2 pF, $l_{BR\text{-}T}/\lambda$ = 1.248, $l_{BL\text{-}T}/\lambda$ = 1.717, f = 32.5MHz)

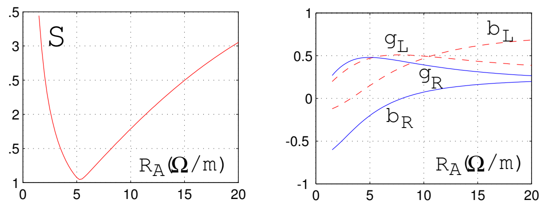

Fig.6 Matching characteristics of the symmetric excitation of the antenna pair (C_{pR} = 80.4 pF, C_{pL} = 80.4 pF, $l_{BR\text{-}T}/\lambda$ = 1.285, $l_{BL\text{-}T}/\lambda$ = 1.855, f = 32.5MHz)

Comparison with symmetric tuning. When $C_{pR} = C_{pL}$ matching by means of $(LS)_R$ and $(LS)_L$ is possible with $g_R = g_L = 0.5$ and $b_R = -b_L$ if the VSWR in the lines B_L-T and B_R-T, $S_R = S_L \geq 2$. This last condition can be fulfilled by the choice of $C_{pR} = C_{pL}$. Fig.6 shows the evolution of S and $y_{TR} = y_{TL}$ as a function of R_A when the matching is adjusted for $R_A = 5\Omega$/m. The matching is only good in a narrow R_A domain. In contrast to the conjugated T case the phase difference between the two straps remains rather constant (here close to π).

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