§11. Characteristics of Conjugate Antenna System

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An ICRF heating and current drive has a serious problem that the reflected RF power fraction is drastically increased due to the large change in the plasma loading resistance such as seen in the H-L mode transition. The injected RF power should be stopped using an interlock system, in which the reflected RF power is monitored whether it is more than the allowable lever for the used vacuum tetrode tube. A ratio of the reflected RF power to the RF forward power, so called the reflected power fraction is usually employed to evaluate the goodness of the impedance matching of the ICRF heating system. Many ideas were proposed and have been carried out in the plasma experimental devices to mitigate the reflected power fraction. In this report a new idea so called "conjugate antenna system" is introduced. It was recently invented and has been researched [1]. Characteristics of the conjugate antenna system are described and its capability is studied for a large change in the plasma resistance, such as occurring in the H-L mode transition.

The conjugate antenna system consists of two antennas as shown in Fig.1. An ICRF (ion cyclotron range of frequency) heating power is divided into the almost same power at the T-junction and fed to each antenna. The imaginary part of the impedance at the T-junction can be an opposite sign each other selecting a proper length between the T-junction and antenna. For the ICH antenna-1 as shown in Fig.1 the RF voltage and current at the T-junction are defined as V_C and I_{C1}, respectively. The normalized length between the T-junction and the ICH antenna is employed A_{AC1}. The RF voltage and current at the ICH antenna are defined as V_{R1} and I_{R1}, respectively. Therefore the resistance of the ICH antenna R_1 is expressed by the ratio of V_{R1} to I_{R1}. The relation of V_C and I_{C1} to V_{R1} and I_{R1} is expressed in the following equation:

$$\begin{pmatrix} V_c \\ I_{c1} \end{pmatrix} = \begin{pmatrix} \cos(2\pi A_{AC1}) & jZ_0 sin(2\pi A_{AC1}) \\ j/Z_0 sin(2\pi A_{AC1}) & \cos(2\pi A_{AC1}) \end{pmatrix} \begin{pmatrix} V_{R1} \\ I_{R1} \end{pmatrix} \quad (1)$$

$$V_{R1} = R_1 I_{R1}$$

Then the I_{C1} is formulated in the following equation:

$$I_{C1} = \frac{jR_1/Z_0(sin 2\pi A_{AC1}) + \cos(2\pi A_{AC1})}{R_1 \cos(2\pi A_{AC1}) + jZ_0 sin(2\pi A_{AC1})} V_C$$

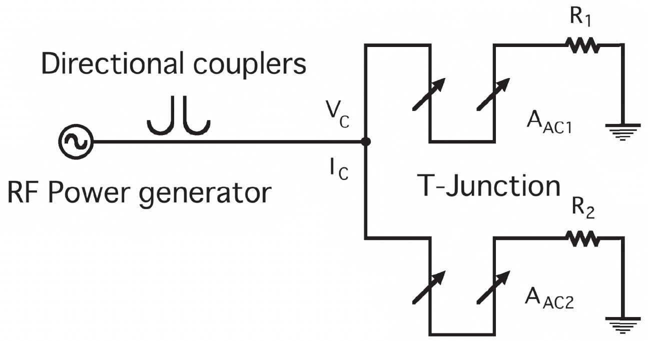

Fig.1 Schematic drawing of conjugate antenna impedance matching system.

For the ICH antenna-2 the I_{C2} can be easily obtained changing suffix 1 to suffix 2 and employing A_{AC2}:

$$I_{C2} = \frac{jR_2/Z_0 sin(2\pi A_{AC2}) + \cos(2\pi A_{AC2})}{R_2 \cos(2\pi A_{AC2}) + jZ_0 sin(2\pi A_{AC2})} V_C$$

At the T-junction the RF current I_C is the summation of I_{C1} and I_{C2}, and the impedance Z is a ratio of V_C to I_C. Then the impedance Z can be calculated in the following equation:

$$Z = \frac{V_C}{I_C} = \frac{A + jB}{C + jD}$$

$$A = R_1R_2 - Z_0^2 tan(2\pi A_{AC1}) tan(2\pi A_{AC2}) \quad (2)$$

$$B = Z_0(R_2 tan(2\pi A_{AC1}) + R_1 tan(2\pi A_{AC2}))$$

$$C = (R_1 + R_2)(1 - tan(2\pi A_{AC1}) tan(2\pi A_{AC2}))$$

$$D = (tan(2\pi A_{AC1}) + tan(2\pi A_{AC2}))(R_1R_2/Z_0 + Z_0)$$

Here to simplify the above equation the resistance of R_2 is assumed to be the same as R_1 and the $tan(2\pi A_{AC1})=-tan(2\pi A_{AC2})$ is employed for the requirement of the conjugate complex of the impedance Z. Therefore

$$Z = \frac{R^2 + Z_0^2 tan^2(2\pi A_{AC})}{2R\{1 + tan^2(2\pi A_{AC})\}} \quad (3)$$

Here $R=R_1$ and $A_{AC}=A_{AC1}$. The impedance matching condition can be obtained at $Z=Z_0$. Then the required length of the transmission line is calculated for various normalized resistance in the following solution;

$$tan^2(2\pi A_{AC}) = \frac{R_N(2 - R_N)}{1 - 2R_N} \quad (4)$$

Here R_N is a normalized resistance by the characteristic impedance of the transmission line Z_0, i.e., $R_N=R/Z_0$. As shown in Fig.2 a solution of the normalized length of the transmission line A_{AC} is plotted for the normalized antenna resistance R_N. When R_N is increased, A_{AC} becomes longer.

[1] A.Messiaen et al., Nuclear Fusion, **46**(2006), S414-S439.

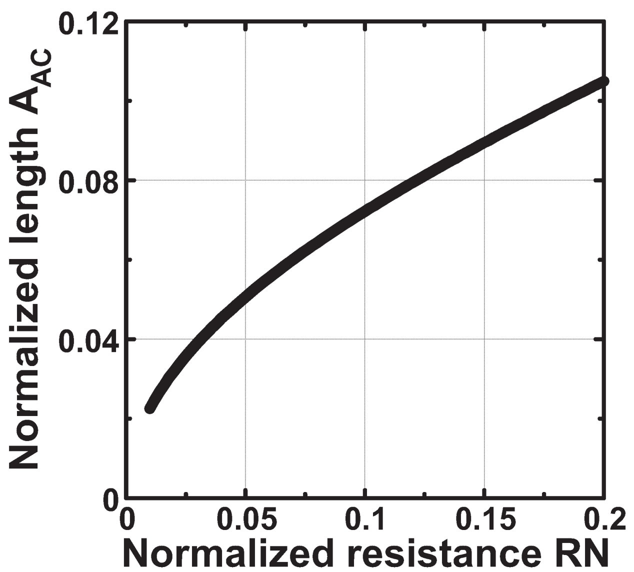

Fig.2 Impedance matching condition in conjugate antenna system: normalized length vs. normalized resistance.