# §9. New ICRF Antenna Design with Controllable Parallel Wavenumber in LHD

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Steady-state-operation (SSO) is very important issue for reactor relevant plasma, and Large Helical Device (LHD) has been achieved the world record for total input power of 1.6 GJ with ion cyclotron heating (ICH) and electron cyclotron heating (ECH) at 9$^{th}$ campaign (Feb., 2006). Long pulse discharges are usually terminated by radiation collapse, when impurities (mainly Fe) are suddenly injected. Additional electron heating mitigates the decrement of electron temperature around plasma center, and the plasma duration could be kept even if impurity was injected. Sheath loading in front of ion cyclotron range of frequencies (ICRF) antenna is candidate for the causes of impurity injection, and large heat flux driven by sheath loading strike to specific diverter plates. When the injected energy of radio-frequency (RF) wave transgresses to threshold energy, sparks are often observed and the increase in impurity is happened.

In LHD there are three pairs of single loop ICRF antennas at 3.5, 4.5, 7.5 port, and higher sheath loadings are predicted rather than double loop type ICRF antennas. In tokamak experiments, double loop type ICRF antenna with the phase difference of 0-pi could reduce sheath loading, and new ICRF antenna design with controllable parallel wavenumber is performed to reduce sheath loading. The purpose of this new ICRF antenna as a heating tool is to expand heating regime to super dense core plasma (SDC) and high beta plasma with low magnetic field, and the purpose of that as a measurement tool is electro-static wave detector with good sensitivity. Ion Bernstein wave is electro-static wave, which is strong related to ion temperature, and we have a plan to measure the ion temperature using electro-static wave measurement.

To design double strap ICRF antenna, radiation characteristics for single strap antenna are studied in various frequencies using high frequency structure simulator (HFSS). To reduce calculation time and memory of PC, simple antenna model is used because there is not so much difference between the actual three-dimension antenna model and simple square-shape antenna model in radiation characteristics. Figure 1 shows the strap height dependence for various ICH experiment frequencies, and three kinds of frequencies 28 MHz, 38.47 MHz, 77 MHz are often used for mode-converted ion Bernstein wave heating (MC-IBW), minority heating (MH) and second harmonic fast wave heating (2$^{nd}$ ICH). As strap height is increased, the resonant frequency of the antenna model is decreased. Antenna strap is not only the wave radiation part but also the electrical circuit as one of an impedance matching device. The resonant frequency of antenna model calculation is around 40 MHz, and it is roughly consistent with the plasma experimental results. RF current profile on strap surface is not drastically changed around the resonant

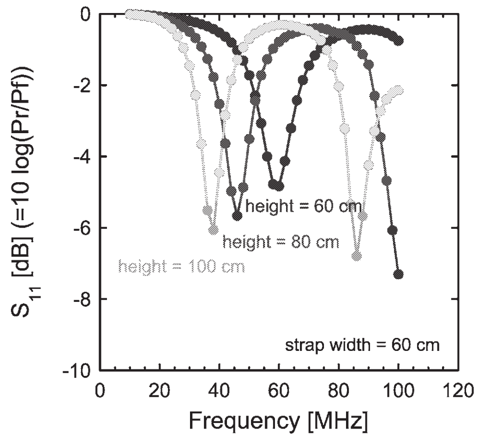


Fig. 1. Resonant frequencies dependence for several antenna heights. $S_{11}$ means the reflective power (Pr) ratio. As strap height is increased, resonant frequency is decreased.

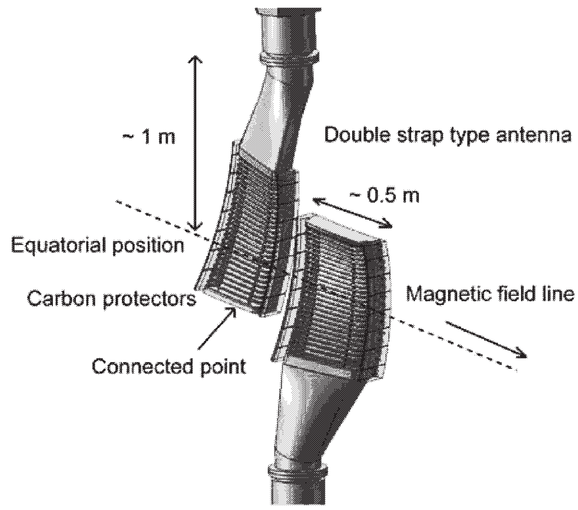


Fig. 2. New ICRF antenna design with controllable parallel wavenumber in LHD. The antenna consists of two single strap antennas, and these antennas could separately move to radial direction to plasma.

frequencies, and the RF current on the strap surface beside plasma is concentrated on both strap edge along magnetic field. To increase antenna loading at MC-IBW, which is post-MH scenario for SSO in LHD, antenna height must be extended rather than that in present.

Figure 2 shows the new ICRF antenna model for double strap type in LHD, and two single straps exist on along magnetic filed line. Magnetic configuration is very complicated around super conducting coils, and we select obliquely-crossed antenna shape to simplify the antenna geometry around plasma surface. Faraday shield angle is 12 degrees, and the antennas could move to radial direction to change the antenna-plasma distance. RF current is concentrated on the connected point (see Fig. 2), and we have to bring these points close to each other to excite fast wave with high wavenumber effectively. High wavenumber excitation is important issue for SDC and high beta plasma heating, and strap width is decreased and both straps are closed.