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It is important for the plasma heating by ECH to transmit oscillated power effectively from each gyrotron with frequencies of 84GHz, 82.7GHz and 168GHz for the LHD in NIFS. The operation of high power gyrotrons depends on the transmission efficiency. The transmission efficiency from a gyrotron window to a LHD vacuum window should be improved from a low level of 65%. Main issue is low transmission efficiency and coupling efficiency in MOU (Matching Optics Unit). There are many miterbends and long waveguide up to the LHD. The MOU that consists of four mirrors couples the RF power of gyrotron with waveguides and but the coupling efficiency is not sufficient. We decided to improve these parts.

The route of transmission line should be modified to reduce the number of miterbends and the length of waveguide. We constructed to connect from the MOU to an antenna with minimum bending and distance on existing structure. Here, the line was aligned by a He-Ne laser again. As a result, the number of miterbends and distance were decreased about 10% and 5%, respectively, in each transmission line.

The low transmission efficiency in the MOU seems to be the RF beam configuration from our perspective. RF beam profile from the gyrotron is very complicated, not like a Gaussian. It is necessary to convert the RF beam including higher order modes to fundamental HE\textsubscript{11} mode for transmission in a circular corrugated waveguide. The arcing or the production of reflected waves may happen in the MOU or transmission line unless the high coupling efficiency is achieved. Besides, spurious RF unconverted to HE\textsubscript{11} mode has to be removed before being injected to waveguide. The improvements are change in mirrors in the MOU and to reform the MOU itself. In the MOU two mirrors are used to focus and the other two mirrors are to adjust, but for their low efficiency the former were replaced with phase retrieval. The size of the MOU box was so small that it was enlarged to place the absorber for the purpose of elimination the scattered RF inside the MOU.

In order to deduce the improved transmission efficiency, the transmitted power is measured by a calorimeter at the positions where is just after and far away from the MOU (about 50m). Finally, we could get the estimation of injection power to the LHD and reliability of transmission lines. The test result is shown in Fig1. In the MOU, there is a good coefficient of coupling at each line. But there is the waveguide line with decreasing efficiency slightly.

By adopting the phase retrieval mirrors, these modifications contribute to the improvement of transmission efficiency. Therefore we could inject as much power to the LHD as possible from each gyrotron on 4th experimental campaign. We obtained robust operation of ECH systems with the arc detectors, and the power monitors. Total injected power by five gyrotrons could be achieved as same as that of six gyrotrons at 3rd experimental campaign. In next experimental campaign we will be able to heat the plasma and carry out various experiments with these improved transmission lines at higher power level together with additional two gyrotrons.

![Fig. 1. The measured and estimated transmission efficiency. Solid lines and dotted lines indicate measured present and previous, respectively.](image1)

![Fig. 2. The phase retrieval mirror with non uniform surface for 84GHz gyrotron. The square size is 1 by 0.8-inch. It is made from Aluminum.](image2)