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Development and test of decoupler for ICRF antenna in EAST

Gen Chen*, Yuzhou Mao, Yanping Zhao, Shuai Yuan, Xinjun Zhang, Chengming Qing

Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China

HIGHLIGHTS

- The mechanism of decoupler for ICRF antenna is proposed.
- Three candidate assembly positions for the decouper can be used.
- The performance relies on the ohmic dissipation and the assembly position of decoupler.

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ABSTRACT

Ion Cyclotron Range of Frequency (ICRF) heating has been adopted in EAST tokamak as one of main auxiliary heating methods. The ICRF antenna usually consists of multiple launching elements because of limited port and space of tokamak device. Mutual coupling between straps has been observed in previous EAST ICRF current drive experiments. Due to adverse effects of such mutual coupling, many issues induced by cross power cannot be ignored, such as power imbalance in feed lines, high voltage standing wave ratio (VSWR), and etc.

To restrain such mutual coupling, A device named decoupler was developed and tested in EAST ICRF system. According to the admittance matrix of load, three assembly positions (oscillation position, optimum position, and smooth position) along transmission line for the decoupler were taken into account and tested. The test results showed that ohmic dissipation in decoupler could not be neglected, which partly influenced the decoupling performance. The oscillation position and optimum position could restrain such adverse effects of ohmic dissipation and showed good decoupling performance. However, they cannot ensure the steady operation during H-mod due to the load variation. Finally, the smooth position has been adopted for EAST I port antenna because of steady decoupling performance comprised with engineering error and load resilience, which sincerely enhance the capability of system operation.

1. Introduction

Ion Cyclotron Range of Frequency (ICRF) heating, which is one of most successful auxiliary heating methods, has been adopted on many tokamaks. The ICRF antenna used to transmit RF power into plasma bulk usually consists of multiple straps because of limited port and space of tokamak device. In previous researches, the mutual coupling, which is depend of the antenna geometry and the plasma, has been observed and challenged the steady-state operation of ICRF system [1]. Due to strong magnetic coupling between straps, many issues induced by cross power cannot be ignored, such as power imbalance in feed lines, high voltage standing wave ratio (VSWR), and etc. In many tokamak devices, a device named 'decoupler' is used to restrict the adverse influences of such mutual coupling [2–5].

In EAST, ICRF heating as one of main auxiliary RF heating methods has been fabricated since 2012. The power capacity of source system is about total 12MW in continuous wave (CW) mode. The source system consists of eight transmitters which can give out maximum output power of 1.5MW each with working frequency of 24–70 MHz. Two ICRF antennas each consisting of 4 straps have been installed at B port and I port, respectively. The antennas are designed to achieve not only auxiliary heating but also current drive. However, in current drive cases, strong mutual coupling among straps has been observed in previous experiments which sincerely affect the steady operation and control of system. It is necessary to develop decouplers for ICRF antennas in EAST to keep power balance in feed lines and ensure the whole system controllable [6–8].

* Corresponding author.
E-mail address: chengen@ipp.ac.cn (G. Chen).

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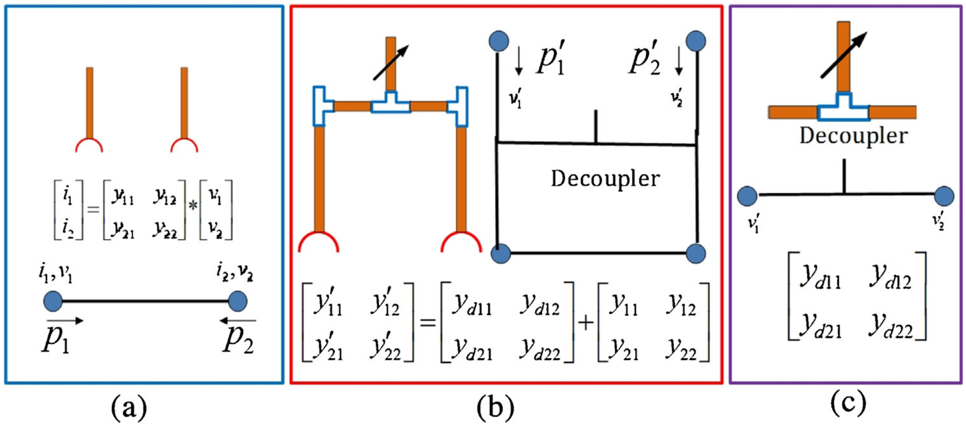

Fig. 1. Block diagram of two port decoupling network.

The rest of this paper is organized as follows. In Section 1, the design and bench test of decoupler is introduced. In Section 2, the assembly of decoupler, which significantly influences the function and performance of decoupler, is discussed in details. Section 3 presents the experiment results of decoupler used in EAST. Conclusion of results and discussion of future works are given in Section 4.

2. Design of decoupler

The straps of antenna with mutual coupling can be described by using a two-port network [3,4]: $Y = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$, as shown in Fig. 1(a). The currents flowing into feed point 1 and 2 can be easily expressed by the admittance matrix of the two-port $\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$ network and voltages at two feed points:

Then the cross power induced by such mutual coupling can be written by $p_{1,2} = \frac{1}{2} Im\left[y_{12,21}\right] \sin\left(\Delta\varphi_{12,21}\right) |v_1||v_2|$[5], where $\Delta\varphi_{12,21}$ is the differential phase of incident voltage at two feed points and $Im\left[y_{12,21}\right]$ is the imaginary part of matrix element $y_{12,21}$. A large cross power could occur between the coupled straps during operation with $\Delta\varphi_{12,21}$ of other than 0 or 180°.

The decoupler is a device with variable admittance matrix connected in parallel, as shown in Fig. 1(b). The variable admittance matrix of decoupler is expressed as: $\begin{bmatrix} y_{d11} & y_{d12} \\ y_{d21} & y_{d22} \end{bmatrix}$, as shown in Fig. 1(c). Then, the shunt admittance matrix composed of feed points and decoupler is: $Y' = \begin{bmatrix} y'_{11} & y'_{12} \\ y'_{21} & y'_{22} \end{bmatrix} = \begin{bmatrix} y_{d11} & y_{d12} \\ y_{d21} & y_{d22} \end{bmatrix} + \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$. The cross power can be rewritten as: $p'_{1,2} = \frac{1}{2}\left\{Im\left[y_{12,21}\right] + Im[y_{d12,21}]\right\} \sin\left(\Delta\varphi_{12,21}\right) |v'_1||v'_2|$, where v'_1, v'_2 are voltages at feed points with decoupler in paraller. As long as $Im\left[y_{d12,21}\right] = -Im\left[y_{12,21}\right]$, the cross power is zero, and then two feed points are isolated with arbitrary $\Delta\varphi_{12,21}$.

Therefore, the design of decoupler should respect two significant requirements: 1) tunable admittance matrix to offset imaginary part of off-diagonal elements $Y_{12,21}$; 2) easy achievement on structure and easy connection to two feed points. The configuration based on coaxial line and T-type connector has been adopted for decoupler in EAST, as shown in Fig. 1(b)&(c). The admittance matrix of decoupler can be varied according to the length of short-terminated tuner in parallel.

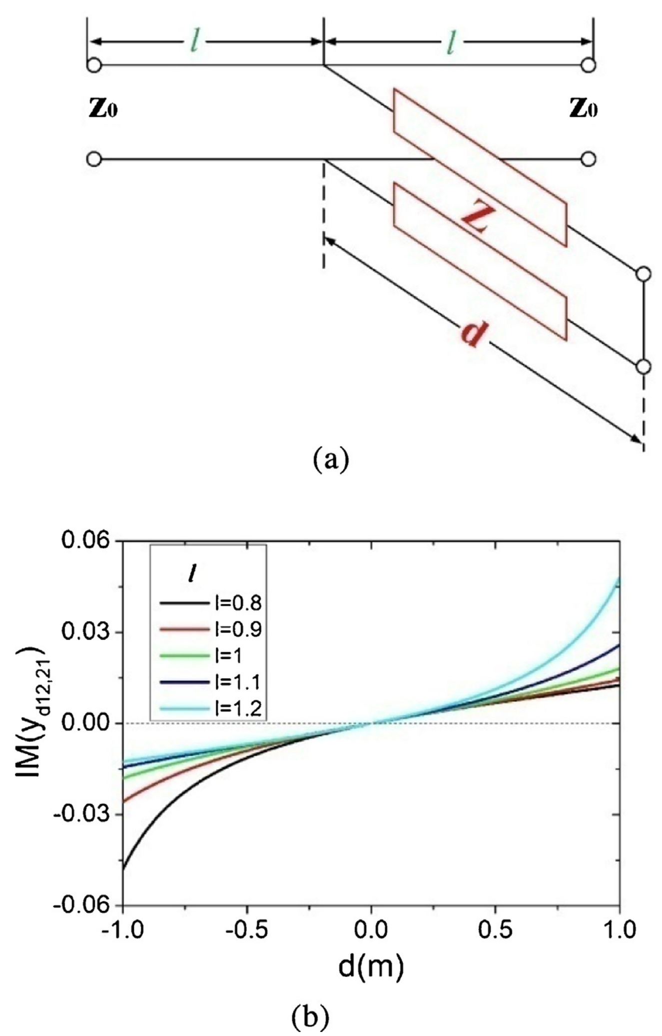

Fig. 2. (a) The equivalent circuit of decoupler T-type tuner, where Z and d is the characteristic impedance and length of tuner, respectively. Z_0 is the characteristic impedance of feed point, and *l* is the length of two arms connected to feed points in parallel. (b) Imaginary part of y_{21} as function of *d* and *l*, while *l* is normalized to $\lambda/4$.

Fig. 2(a) showed the equivalent circuit of decoupler with T-type tuner, where Z and d is the characteristic impedance and length of the tuner, respectively. Z_0 is the characteristic impedance of the feed point, and *l* is the length of two arms connected to feed points in parallel. The admittance matrix of the decoupler is mainly