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Millimeter Fast Directional Switch System for the NTM suppression Experiments on JT-60SA

JT-60SA でのNTM 抑制実験に向けたミリ波高速スイッチシステムの検討

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A FAst DIrectional Switch (FADIS) performance based on steep slope in a diplexer function has been considered for dual-frequency (dual-*f*) applications to switch the transmission line with small frequency control. A diplexer of a FADIS using a Square Corrugated Waveguide (SCW) splitter was designed as one of most attractive candidates for the dual-*f* operation on the JT-60SA system. The splitter performance was a key issue for the dual-*f* operation, and extended operation regions in splitter operations have been considered using mode contents analyses based on matching coefficient evaluation. Some operational branches with high matching coefficients (> 0.9) were found, and new operation parameters were proposed for the dual-*f* application. Radiation pattern distributions from the SCW splitter were defined very well with no serious side lobes. Double loop resonant ring system has been proposed with the SCW splitter for the dual-*f* operation.

1. Introduction

Local current generation by Electron Cyclotron Current Drive (ECCD) has been used to suppress Neoclassical Tearing Mode (NTM) activities in many fusion experimental device, tokamaks such as JT-60U, ASDEX-U, DIII-D. Synchronous switched injection for mode rotation of the NTM magnetic island has been proposed as a more effective suppression method relative to the continuous injection. Up to now, the synchronous injection was based on incident power modulation of high power mm-wave tubes (gyrotron). The power modulation has the disadvantage that half of the available power is out of use. An attractive alternative of the synchronous injection is switching of the launchers, *i.e.* directing the incident beam to different poloidal and/or toroidal ECCD positions. A FADIS system has been proposed and developed to switch fast the transmission lines and the launchers of the ECCD injection. The dual-*f* [110/138 GHz] gyrotron has been developed for the JT-60SA project [1]. Note that the FADIS operation is based on steep slopes in the diplexer transmission function leading to switching upon a small frequency shift. The gyrotron oscillating frequency can be controlled by a ratio of gun-anode to gun-collector(body) voltages, but it is drifting due to thermal expansion of the gyrotron cavity in general. Frequency drift and dip in the gyrotron operation were measured to consider which kind of FADIS is preferred for the JT- 60SA project under conditions listed in Table I. A SCW diplexer system was considered as one of the most attractive FADIS systems for stable high-power and Cyclotron Heating and Current Drive (ECHCD) system for the JT-60SA project, because there is no risk to damage fragile parts like CVD-diamond disks, and no limitation of the operating polarization in principle [2].

Table I. Design conditions and targets of FADIS

Subject	Parameter
Operating frequency	110/138 GHz
Frequency dip	4 MHz
Switching frequency	10 MHz
Synchronous modulation rate	> 80 %

2. Splitter / Combiner Performance

A SCW of $L_{SCW} = 2a^2/\lambda_0$ can be used as a splitter of an input beam into symmetric and anti-symmetric directions. Here L_{SCW} and a were waveguide length and side of the square, respectively. λ_0 was wavelength at the operating frequency in vacuum. The dual-*f* operation is impossible in the traditional splitter concept of L_{SCW}

$= 2a^2/\lambda_0$. Extended operation regions for a diplexer have been considered by Matching Coefficient (MC) analysis. Figure 1 shows a contour plot of MC (>0.9) for the beams excited at the outlet aperture, as a function of L_{SCW} and incident angle of the beam coupling θ_{in} for the 110 and 138 GHz operations. The side a of the square aperture was 0.0534 m. High MC operational region is found for the normal and the 3rd extended branches at L_{SCW} = 2.0 m and θ_{in} = 17.5 degree for 110 and 138 GHz, respectively. Figure 2 shows field intensity and phase distributions, $I(x)$ and $\varphi(x)$, radiated from the SCW at 110 and 138 GHz in the normal and 3rd operational branch operations, respectively. The radiation fields were evaluated by the developed Kirchhoff integral code at the z = 0.2 m. The beams were obliquely injected at θ_{in} = 17.5 degree in the x-z plane. The phase distribution $\varphi(x)$ was $k_x\, x$ profile, where k_x was a wavenumber component in the x direction. The k_x profile, which was the derivative of $\varphi(x)$ on x, showed the propagating direction in the x coordinate. Local output angle profile $\theta_{out}(x)$ in the x direction determined by $\sin^{-1}[k_x(x)/k_0]$ is also shown in the figure. Here, k_0 is the wavenumber in free-space propagation. The main lobes of the two split beams were properly obtained at the output angle of 17.5 degree in response to θ_{in} =17.5 degree at both the frequencies.

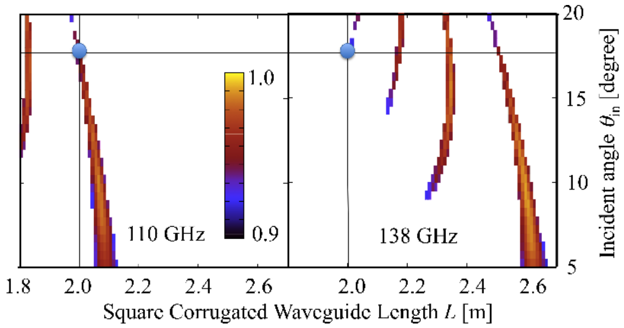

Fig.1 Contour plot of MC (>0.9) analysis for the 110 and138 GHz operations.

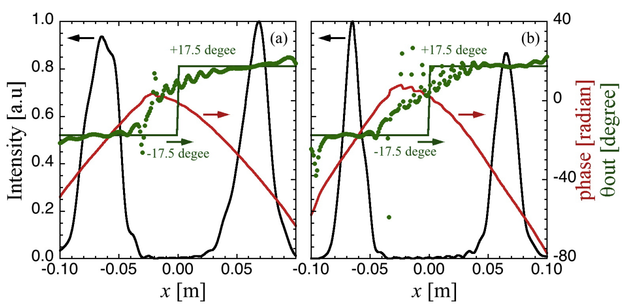

Fig.2 Radiated intensity and phase distributions, $I(x)$ and $\varphi(x)$ for the 110 and138 GHz operations.

3. Resonant Ring

The resonator type diplexer with the SCW splitter has been considered for the JT-60SA ECHCD system. Figure 3 shows the resonant cavity dependences of the two FADIS outputs in the single and double resonant rings with the SCW splitters of L_{SCW} = 2.0 m for the dual-f operations. In general, a wavelength λ_g defined in a so large oversized SCW can be approximated to λ_0. The period of the resonant cavity dependence on the frequency Δf is about c/L_{total} at $\lambda_g \sim \lambda_0$ as shown in the figure. Here c and L_{total} are the speed of light and the round-trip length of the one resonant ring, respectively. The switching properties do not depend on the operating frequency itself, but the slope of the resonance is not sufficiently steep to switch the outputs by a 10 MHz frequency shift with the frequency dip of 4 MHz in the single loop resonator ring. The Q value in the resonant cavity is determined by coupling C, transmittance T and L_{total}. Allocation of C and T is difficult in the SCW diplexer, and L_{total} was already selected for the dual-f operation. The Q value of the cavity resonant dependence cannot be adjusted by (C, T, L_{total}) parameters. Therefore, a double loop resonant cavity system has been proposed to obtain high-Q performance. The outputs can be switched by the 10 MHz frequency shift with the frequency dip of 4 MHz in the double loop resonant diplexer for both operating frequencies. The SCW diplexer of the double loop resonant ring is useful for the dual-f operation of the JT-60SA ECHCD system.

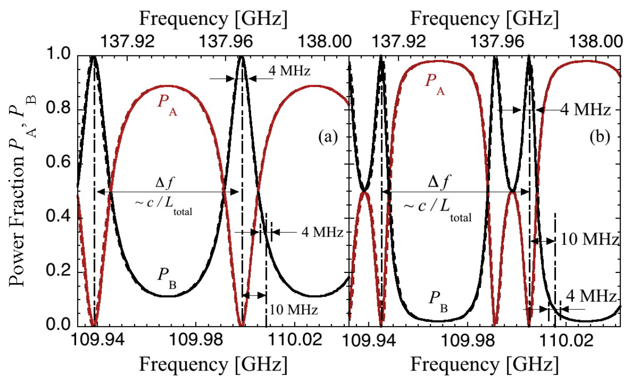

Fig.3 Resonant cavity dependences of the two FADIS output P_A and P_B in the (a): single and (b): double resonant rings for the dual-f operations.

Acknowledgments

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