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Design and RF Test of Broadband Coaxial Hybrid Splitter for ITER ICRF System

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1. Introduction

The ICRF system of the ITER is required to couple 20 MW to the plasma in the 40~55 MHz frequency band for RF heating and current drive operation [1]. The corresponding matching system of ICRF antenna must be load-resilient for a wide range of antenna load variations due to mode transitions or edge localized modes. Indeed the use of hybrid splitters ensures that no reflections occur at the generator when the reflections on the adjacent lines are equal both in magnitude and in phase, in which case all reflected power will not be seen by the generators and will be returned to the dummy loads. Most 3 dB coaxial hybrid circuits installed and implemented on the ICRF system is single section coupler providing best performance at the design frequency with narrow bandwidth. The bandwidth of such a single-section 3 dB hybrid coupler is limited to less than 20% due to the quarter wavelength transmission line requirement. The amplitude balance becomes rapidly degraded away from the center frequency. We designed, fabricated and tested a high power, ultra-wideband two-section 3 dB coaxial hybrid coupler over all frequencies from 40 MHz to 55 MHz for ITER ICRF system by configuring asymmetric impedance matching.

2. High power waterload with a cone-shaped quartz

2.1 HFSS simulation results

A schematic diagram of the wideband two-section hybrid is shown in Fig. 1. We designed a 3-dB coaxial hybrid coupler at the operating frequency from 40 MHz to 55 MHz for load resilient ICRF heating and current drive at the ITER ICRF. We have used a three-dimensional electromagnetic simulation code, HFSS [2], to design wideband hybrid coupler with good performance in amplitudes and phase balances of asymmetrically impedance matched two-section hybrid coupler. Simulation results are presented concerning the effects of this asymmetric impedance matching in 3 dB hybrid coupler for wide bandwidth, amplitude and phase balance. In the case of the single or two-section 3 dB hybrid couplers, the best performance at the center bandwidth frequency can be obtained with the condition of Z_2 = 35.4 Ω [3]. Fig. 1 shows the optimized impedances of main and coupled transmission line to obtain wideband frequency performance over all frequency bands with double-section hybrid splitter. By asymmetrically reducing the impedances of the main and coupled lines by 26.3% and 23%, respectively, in comparison to the original values of the conventional 3 dB two-section hybrid, we realized that the bandwidth of the proposed circuit is not only wider than that of the conventional three-section coupler, but also that the bandwidth is almost twice wider than that of the conventional two-section hybrid coupler while maintaining the overall size of the hybrid coupler. Fig. 2 shows the simulation results of the wideband hybrid splitter. As shown in Fig. 2, HFSS simulations predicted that the two-section hybrid coupler can obtain an excellent coupling flatness of –3.1 ± 0.1 dB and 90 ± 2° phase difference over the frequency range of 40~55 MHz. The input VSWR obtained is less than 1: 1.1. The simulated S21 and S31 of the hybrid splitter were obtained an amplitude imbalance of 0.1 dB over all frequencies from 40 MHz to 55 MHz.

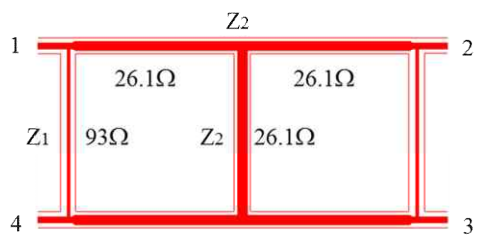


Fig. 1. Schematic diagram of a wideband hybrid for ITER ICRF system.

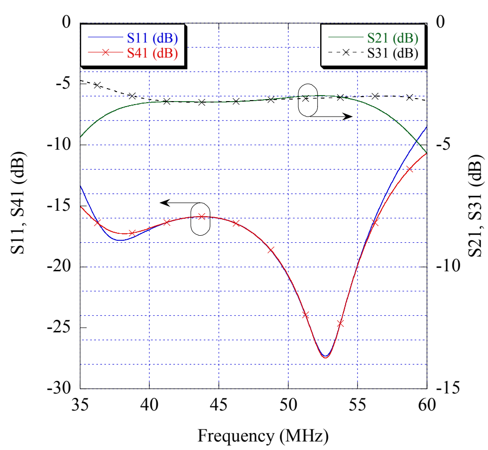
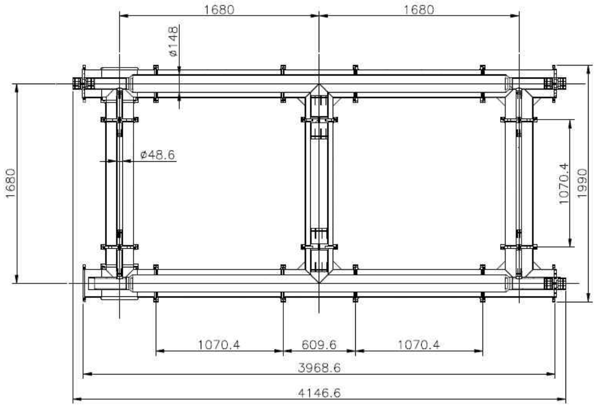


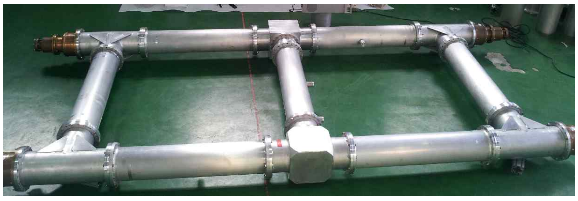
Fig. 2. S-parameters of ITER ICRF hybrid splitter obtained from HFSS simulation.

2.2 3-D modeling and RF test results

Fig. 3 shows the 3-d model and RF test set-up of wideband hybrid splitter. Fig. 4 shows the measured S-parameters of the 3-dB hybrid splitter. The measured S21 and S31 over all frequencies from 40 MHz to 55 MHz are about –3.1 ± 0.1 dB. The reflection and isolated coefficients are over -15 dB at the band edges. The measured RF performances of the hybrid splitter are in good agreement with the simulation data.



(a)



(b)

Fig. 3. (a) 3-d model and (b) fabricated double section hybrid splitter.

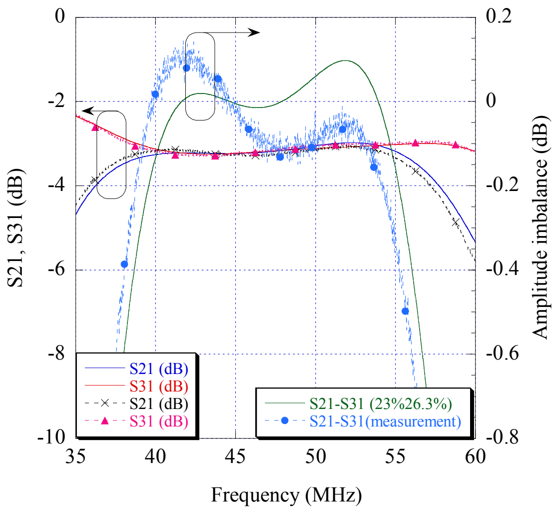


Fig. 4. Simulated and measured S-parameters and amplitude imbalance over the ITER ICRF frequency band.

3. Conclusions

We have designed, fabricated, and tested a 3-dB wideband hybrid coupler for stable and load resilient operation of the ITER ICRF system. The wideband two-section 3-dB coaxial hybrid coupler was well designed by configuring asymmetric impedance matching using HFSS. In the rf measurements, we found that wideband hybrid splitter has an amplitude imbalance of 0.1 dB over all frequencies from 40 MHz to 55 MHz. We expect that wideband hybrid splitter will be applicable to ITER ICRF matching system for load resilient operation at fusion plasmas.

Acknowledgements

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