# Simulation of electron density measurement in Taban tokamak via reflectometry system

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## Abstract

Since some tokamaks such as Taban are currently working with low density plasma, a fixed frequency reflectometer system was designed and constructed to monitor plasma production within the vacuum vessel. The system consists of a circular waveguide-antenna, a phase detector, bi-directional coupler and an RF signal generator. The waveguide antenna is working as both transmitter and receiver to measure the phase difference of transmitted and received signals. In order to evaluate performance of the antenna and also to predict the experimental result of electron density measurement in Taban tokamak, the process of electromagnetic wave transmitting from and receiving to an antenna model were simulated via CST software. The simulation were conducted within the reflectometer frequency range (1.7-2.5 GHz), which the plasma area was modelled so that to have the frequency of 2.4 GHz. In this paper, the simulations and their results will be presented in detail. Based on the simulation results, the reflectometer antenna performed appropriately all over the working frequency, since it could properly transmit and receive electromagnetic wave to and from the cut-off layer of the plasma.

**Keywords**: electron density, reflectometry, tokamak, antenna design

## Introduction

Microwave diagnostic methods such as reflectometry have been widely used to measure the electron density profiles in tokamak plasmas. Since the location of the reflected wave depends on the local plasma density, it can be changed by varying the incident wave frequency. Electron density information can be achieved from the phase measurement of the reflected wave, through two methods [1]. In the simpler method, fixed-frequency reflectometers are used which consist of simple and inexpensive components. In this kind of reflectometer the system operates at a single fixed frequency. For instance, in LDX Tokamak, an O-mode reflectometry system, working in 4-8 GHz frequency range, has been applied for low density plasma measurements [2] and recently, a frequency modulated reflectometry system sweeping in the V-band frequency has been developed on the EAST Tokamak [3]. In 1961, Anisimov et al. claimed the possibility of measuring plasma density profiles using microwave reflection [4]. They used fixed-frequency microwaves to obtain the maximum electron density as well as the profile shape [5]. A simple fixed-frequency microwave reflectometer was used in the JET

Tokamak device for plasma density profile measurements in 12–18 GHz frequency range [6]. Recently, an investigation on NSTX is facilitated by an array of fixed-frequency reflectometers in 30–75 GHz frequency range used to determine the radial density perturbation structure [7]. Similar to the works in literature, an O-mode fixed frequency reflectometry system was designed, simulated and constructed to monitor low plasma density [8]. In this paper, the procedure of the electromagnetic wave launching and receiving to the modelled antenna were simulated via CST software.

**Description of the antenna model**

The designed reflectometry system for Taban tokamak consists of a microwave source, a directional coupler, phase and gain detectors and a waveguide-antenna. The circular waveguide-antenna is usually applied for reflectometry systems. Here, to provide the adaptability between the shape of the vacuum vessel window and the antenna, a single circular waveguide-antenna with coaxial transition line was considered for launching and receiving the microwave. The distance between the probe and the back side of the waveguide was tuned to about one quarter of the wavelength, to achieve the impedance matching. The distance between the probe and the aperture should be also considered greater than half of the wavelength to repress higher-order modes inside the waveguide. The schematic of the waveguide-antenna is illustrated in Fig. 1(a). According to the dimensions of the vacuum vessel window, the inner diameter of the waveguide-antenna has to be 10 cm, which leads to cutoff frequencies of 1.76 GHz and 2.5 GHz for $TE_{11}$ (the dominant TE mode in the waveguide) and $TM_{01}$ modes (the first TM mode), respectively. Since the excitation mode of the reflectometry system is TE mode, the waveguide-antenna should operate in the frequency range of 1.76 to 2.5 GHz.
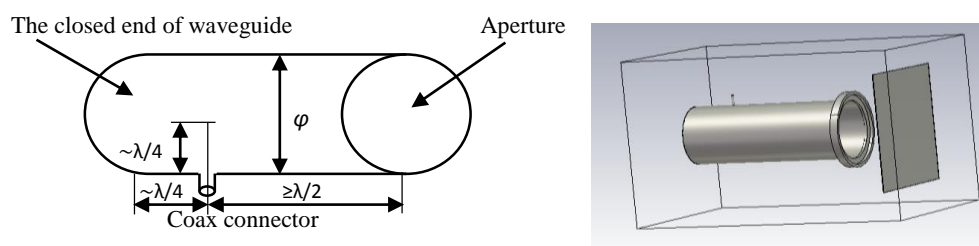


Figure 1: a) The schematic of coax to circular waveguide transition, b) antenna and plasma model in CST

**Simulation results**

In order to verify the results of experimental tests for determination of plasma electron density in Taban Tokamak, reported in the previous work [8], some simulations have been conducted via Frequency Domain Solver of CST software, in which sending of microwave from the antenna to the plasma and its propagation have been modeled. The microwave frequency range is considered to be from 1.7 to 2.5 GHz. As it was estimated in previous work [8], the plasma

frequency of 2.4 GHz was assigned to the modeled plasma area employing Gyrotropic model. As shown in Fig. 1(b), the plasma area was modeled in a distance from antenna which was estimated before [8]. While plasma was modeled, the microwave propagation in the frequencies of higher and lower than plasma frequency (2.4 GHz) was modeled. In the following, the simulation results will be presented.

Based on the theory of microwave propagation in plasma, In case of perfect performance of antenna, it is expected that the microwave in the frequencies lower than plasma frequency doesn't transmit through the plasma and is reflected from it. On the contrary, in case of microwave with the frequencies higher than plasma frequency, it is expected that microwave transmits through the plasma and isn't reflected from it. Based on the simulation results, for the wave in frequencies higher than 2.4 GHz, only 30% of wave power returns to the antenna aperture (the ratio of received wave to the transmitted one is calculated from the antenna S parameter), which indicates that significant portion of wave transmits through the plasma.
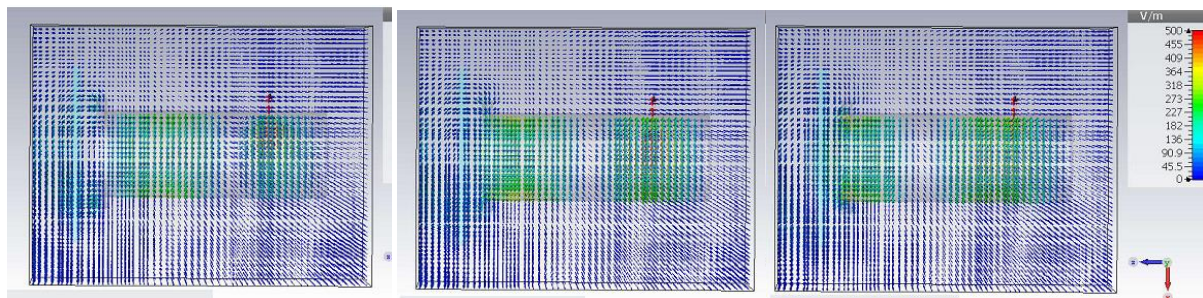


Figure 2: The electromagnetic field of microwave propagation in the frequency of 3 GHz (higher than 2.4 GHz) in different time steps

On the other hand, for the frequencies lower than 2.4 GHz, significant portion of wave is reflected from the plasma. In Fig. 2 the wave propagation in the frequency of 3 GHZ is demonstrated for different times and in Fig. 3 electromagnetic field of microwave propagation in the frequencies lower than 2 GHz is demonstrated in different time steps.
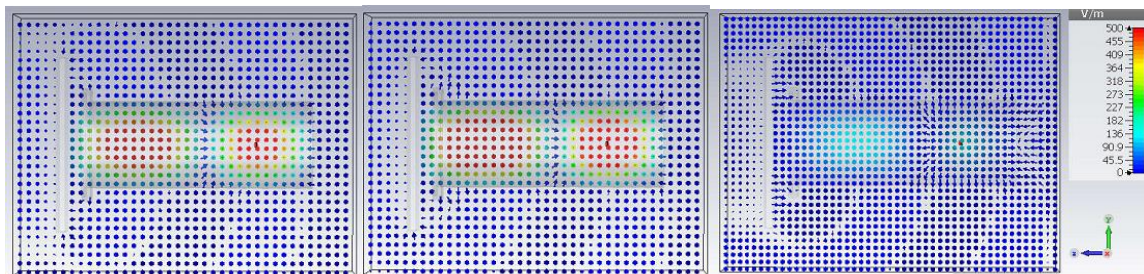


Figure 3: The electromagnetic field of microwave propagation in the frequency of 2 GHz (lower than 2.4 GHz) in different time steps

The motion of microwave toward the plasma and wave transmission through it can be observed in Fig. 2 which relates to the microwave propagation in the frequency of 3 GHz. In the pictures

of Fig. 2, the colored electromagnetic fields before and after plasma domain are indicative of continues movement of microwave toward the far field. Additionally, it is obvious that the pattern on wave propagation rarely affected by the plasma. On the other hand, in the Fig. 3 which relates to the microwave propagation in the frequency of 2 GHz, it can be observed that significant portion of microwave is reflected from plasma. On the contrary of the previous case, the colored electromagnetic fields in the pictures of Fig. 3 demonstrated that there isn't any wave field in the downstream of the plasma domain. Addition to that, it is observed that the microwave propagation is completely affected by the plasma domain.

## Conclusion

Based on the way of microwave propagation for the frequencies of higher and lower than the considered plasma frequency (2.4 GHz), it can be concluded that employing antenna, microwave and plasma models, and the procedure of microwave propagation in the plasma domain of Taban Tokamak was perfectly simulated. Addition to that, good agreement between the simulation results and those which obtained from experiments (reported in [8]), demonstrate that the employed parameters in the simulation such as the plasma frequency (2.4 GHz), configuration of plasma domain and antenna model, the distance between them and etc. was thoroughly selected.

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