Microwave imaging reflectometry for KSTAR

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Introduction

Microwave reflectometry has been widely used for measuring the electron density profile and recently density fluctuations in magnetically confined plasmas. In a conventional microwave reflectometry, the probing wave is launched and received on the equatorial plane using a pair of small horn antennas. The measurement is essentially a point measurement, and does not provide direct information on the spatial structure of the fluctuations [1]. In particular, for sufficiently large amplitude and/or wave number turbulence, the reflected field at the detector plane can become extremely complex due to the wave interference, making it difficult to extract accurate information of the density fluctuations at the cut-off layer.

Studies of this problem led to the development of the microwave imaging reflectometry (MIR) concept [2]. In this technique, large-aperture optics is used to shine the probe beam on a wide region of the cut-off layer, and collect back as much of the reflected beam as possible, and form an image of the cut-off layer onto the 1D array of detectors. The first MIR instrument of this type was installed on the TEXTOR tokamak [3, 4].

KSTAR MIR system

The KSTAR MIR system is being developed to measure 2-dimensional (radial $\times$ poloidal) density fluctuations for turbulence study [5, 6]. The radial coverage is achieved by multi-frequency probe beam sources as the radial position of the cut-off layers is a function of frequency and the poloidal coverage is achieved by illumination of the probe beam onto a wide region of the cut-off layer within the focal depth. The full system, to be installed by 2014, will have 5 radial and 16 poloidal detection channels. The target plasma parameters are $B_t = 3.0 \sim 3.5$ T, $n_e = 2 \sim 5 \times 10^{19}\ m^{-3}$, elongation ~ 1.8, and triangularity ~ 0.6. Prior to the full MIR system, a prototype MIR system with 2 radial and 16 poloidal channels is under development for 2012 KSTAR campaign. The MIR system will share a part of optics, referred as zoom optics, with the planned 2nd ECEI system (identical to the first ECEI system [7]). The

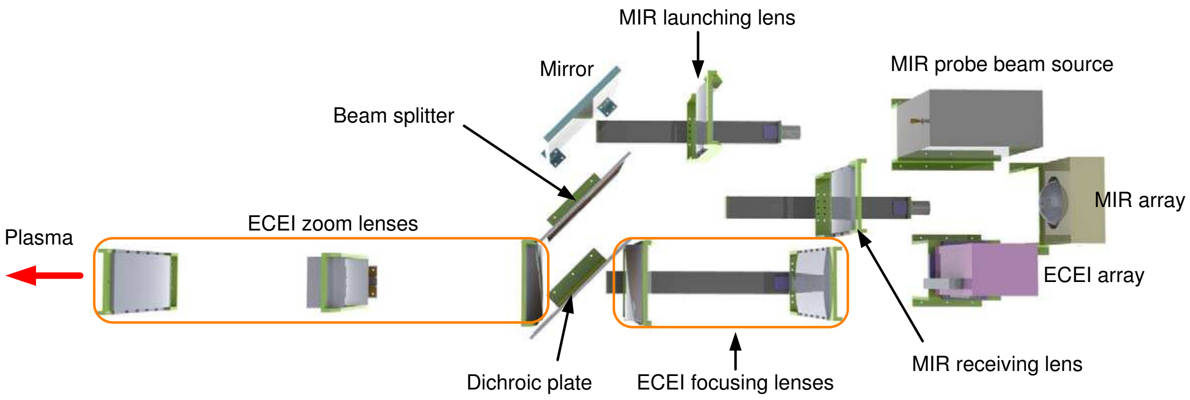

Figure 1: Conceptual design of the combined MIR and 2nd ECEI system on KSTAR.

two system will simultaneously measure the electron temperature and density fluctuations in KSTAR plasmas. Figure 1 shows the combined KSTAR MIR and ECEI system.

Preliminary optics design

There are a few critical points in the design of the launching and receiving optics of the MIR system. The design of the launching optics has to consider the matching condition of the curvature of the probe beam wavefront to the plasma cut-off layer for the optical robustness and the wide coverage of the cut-off layer within the optical depth for resolving the spatial structure of the fluctuations. The receiving optics should restore phase front image of the reflecting layer (i.e., cut-off layer) on the detector plane by collecting as much of the reflected beam as possible using large aperture optics. Although a tall probe beam is required, one should consider the diffraction effect which deteriorates the phase reconstruction especially in the edge channels. Generally, the aperture size is limited by the port size and an optimal probe beam size is determined based on the aperture size and diffraction analysis.

Figure 2 (a) shows the preliminary design of the MIR launching optics. The wavefront of the probing Gaussian beam is matched with the target cut-off layer poloidally and toroidally. The remotely controllable lenses can adjust the curvature radius of the probe beam and focal position depending on the plasma parameters. The beam size is largest at the first zoom lens and will be kept below one half of the lens height to minimize diffraction. The probe beam covers $\sim$ 12 cm poloidal region of the cut-off surface with the spatial resolution of $\sim$ 0.8 cm, as determined by the 16 poloidal channel. The detectable wave number of density fluctuation is $0.5 < k_\theta < 2.1$ cm^{-1}. The receiving optics shown in figure 2 (b) forms the phase image of the cut-off layer onto the 1D array of detectors, which are located just behind the substrait lens.

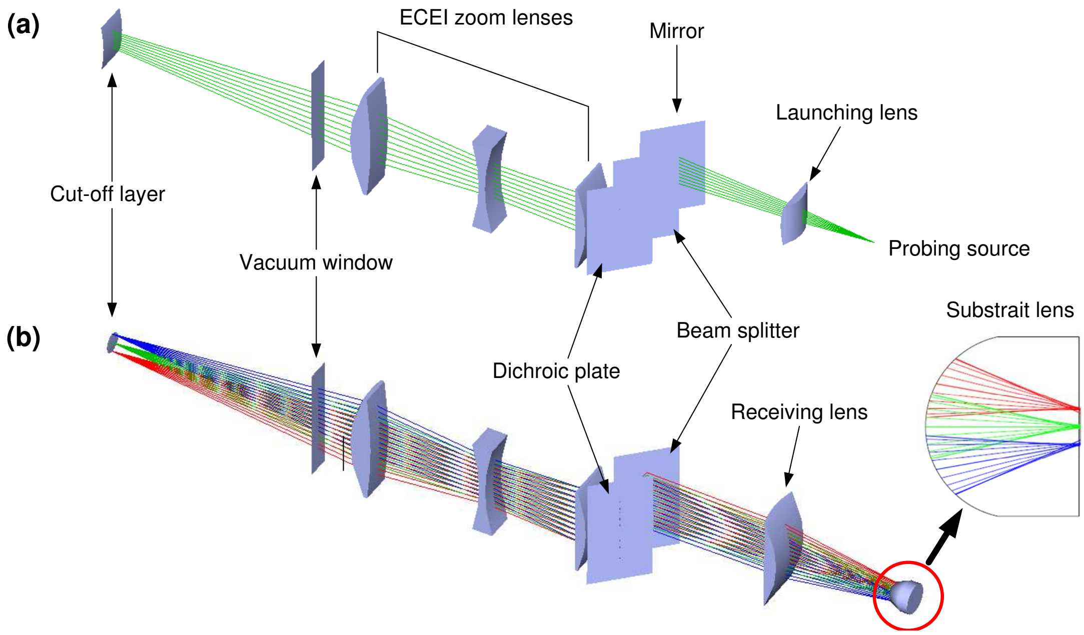

Figure 2: Preliminary design of the KSTAR MIR optics: (a) launching optics and (b) receiving optics

Design of millimeter wave sources and RF electronics

A prototype MIR system will adopt two-frequency (88 and 92 GHz center frequency) millimeter wave source for measuring two separate cut-off layers. The sources have frequency tunability of ± 1 GHz for adjusting the target cut-off layer position based on the plasma parameter. The 88 and 92 GHz probe beam reflect near $r/a \sim 0.5$ in the 3 T plasma and $r/a \sim 0.8$ in the 3.5 T plasma. The two frequency waves are combined in a diplexer and launched toward the plasma through a single launching horn antenna. Two reflected waves from the plasma cut-off layers are coupled to the 16-channel detector array by the receiving optics. The detector down-converts the reflected wave signals from ~ 90 GHz to the intermediate frequency (IF) ~ 1 and ~ 3.5 GHz. In reference channel, 1.0 and 3.5 GHz IF signals drive tracing circuits that generate constant high power reference IF signals. The high power reference IF signal is then split into 16 signals which are transferred to the next mixing stage. The IF signal in detection channel is mixed with the reference IF signal by an inphase-quadrature (I/Q) demodulator and downconverted to the phase fluctuation frequency of the cut-off layer. The I/Q signals are amplified by video amplifiers and recorded by a digitizer with 2 MS/s sampling rate and 14 bit resolution.

Summary

The KSTAR MIR system is being developed to measure 2D image of electron density fluctuation with 2 radial and 16 poloidal channels for 2012 KSTAR campaign. The full system with 5 radial and 16 polidal channels will be installed by 2014. The remotely controllable optics pro-

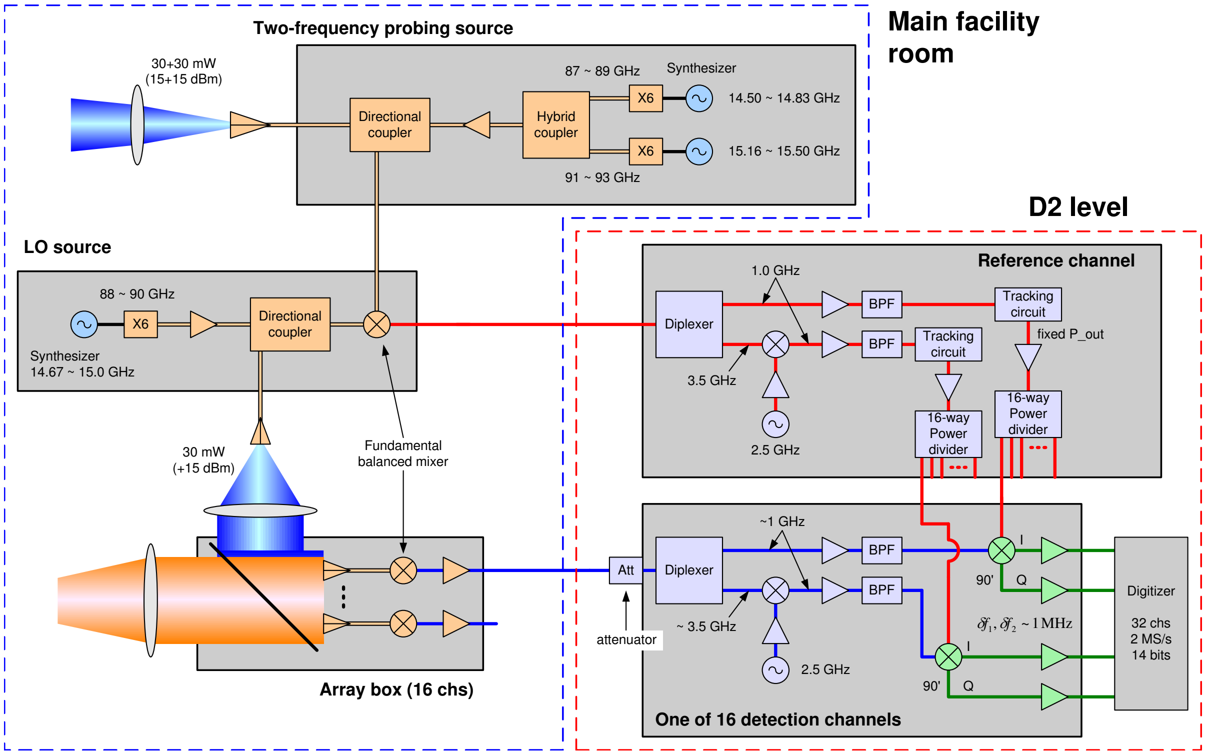

Figure 3: Schematic of the prototype KSTAR MIR system. The system is composed of two-frequency probe beam source, local oscillator (LO) source, 16-channel detector array, and electronics.

vides a wide coverage of the curvature radius of the the probe beam and focal position based on the plasma parameters. The fluctuation wave number can be detectable from 0.5 to 2.1 cm^{-1}. Two frequency millimeter wave sources and the detection system including 16 channel detector array and RF electronics have been designed.

Acknowledgments

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