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Microwave Imaging Reflectometry of Corrugated Metal Targets

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In this paper we compare conventional and imaging reflectometry systems by means of numerical simulation. A corrugated wheel is used as an approximation of the reflections by real plasma fluctuations. Our simulations prove that in the case of conventional reflectometry the correlations between the phase fluctuations of the received signal and the shape of the wheel decrease with an increase in distance from the target to the antenna, while the two-lenses imaging system shows high correlations far from the target.

Keywords:

microwave imaging reflectometry, numerical simulation

Microwave reflectometry is a diagnostic tool which uses reflection of electromagnetic waves at plasma cutoff to measure plasma density profiles and fluctuations. Low requirements to the port access and high localization of the measurements have led this technique to become a common tool in fusion plasma studies. However, scattering by random fluctuations leads to complicated interference patterns far from the reflection point [1]. It thus becomes difficult to extract information regarding plasma fluctuations from the measured signal parameters. As a possible solution of this problem, a microwave imaging reflectometry concept has been suggested. In this technique, large-aperture optics are used to collect as much of the scattered wavefront as possible and to optically focus it onto an array of detectors, thus restoring the integrity of the phase measurements [2,3].

In this paper, a numerical model of electromagnetic wave propagation is developed and applied to a comparison of the conventional and imaging reflectometers.

The present model comprises numerical FDTD and an analytical solution of the 2D Maxwell equations in a linear isotropic nondispersive medium,

$$\frac{\partial \vec{H}}{\partial t} = -\vec{\nabla} \times \vec{E}, \quad \frac{\partial \vec{E}}{\partial t} = \vec{\nabla} \times \vec{H} - \sigma \vec{E}, \qquad (1)$$

where $\vec{H}$ is the magnetic field, $\vec{E}$ is the electric field, σ is the electric conductivity, which assumes non-zero values only on the wheel. Vacuum propagation, phase front correction by the lenses, and reflection from a corrugated metal wheel are taken into account. The wheel is used as an approximation of the reflections by real plasma fluctuations, which are not included into the model at the present stage.

Three types of reflectometer systems are considered: a conventional reflectometer without lenses, and a one-lens system and a two-lenses system as models of the imaging reflectometer (Fig. 1).

In our simulations, the modeled spectrum of irregularities consists of two components: a long wave component with a fixed wave number k_{fix} ($k_{fix} \ll k_0$, where k_0 is the wavenumber of the probing signal) and a component with an arbitrary variable wave number k_{corr} ($k_{corr} > k_{fix}$). Such a choice of spectrum allows us to search for the conditions when both large and small scale fluctuations are simultaneously recovered, *i.e.*, imaged correctly by the reflectometer.

In our model the assumed parameters $k_{fix} = 0.31$ cm^{-1}, $k_0 = 6.28$ cm^{-1}, a radius of the target wheel of $r_0 = 40$ cm, a depth of the wheel corrugation of 0.5 cm lead to the nominal phase fluctuation equal to 2π.

A sample of the computed phase of the received signal

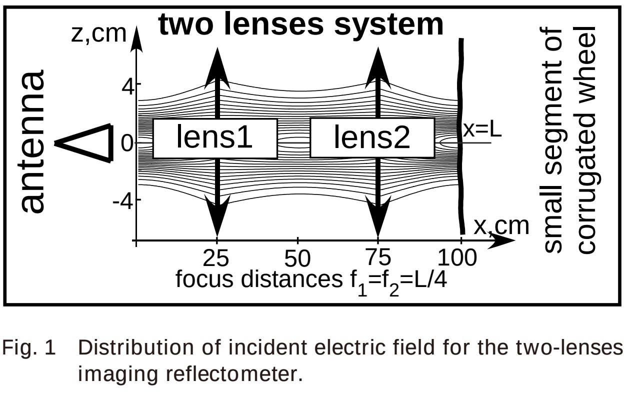

Fig. 1 Distribution of incident electric field for the two-lenses imaging reflectometer.

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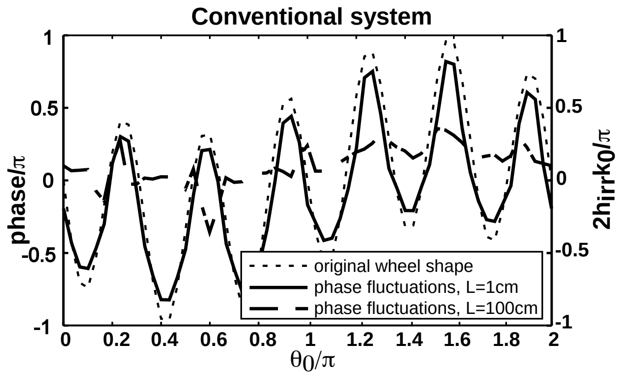

Fig. 2 A sample of phase fluctuations of a conventional reflectometer signal and original surface shape of the wheel. θ_0 is the rotation angle of the wheel and h_{irr} is the height of irregularities. Corrugation wavenumber is k_{corr} = 1.88 cm^{-1}.

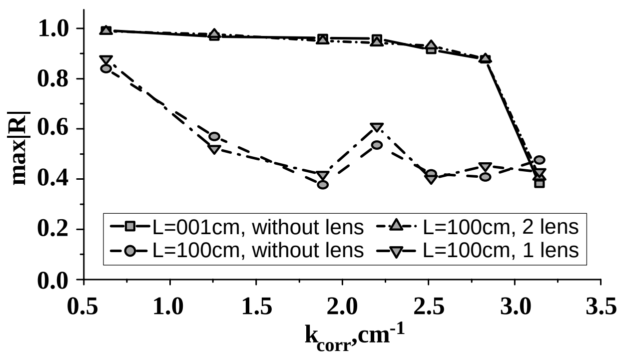

Fig. 3 Maximum of cross-correlation coefficient R between the phase fluctuations of the received signal and the shape of the corrugation at different distances from the wheel to the antenna L.

is shown in Fig. 2 together with the original shape of the wheel corrugations. Obviously, the signal phase reproduces the shape of the wheel surface quite accurately even without any lenses if the receiver is located near the target. This conclusion fails, however, as the distance between the target and the receiver increases (Fig. 2, black broken line). The results shown in Fig. 3 prove that all the systems provide high correlations between the signal phase and the wheel surface profile for small corrugation wave numbers. The conventional reflectometer exhibits high correlations close to the target (L = 1 cm). However, for the longer distance from the target to the antenna (L = 100 cm) the correlations calculated for the conventional system are drastically reduced due to the interference effects. Depending on k_{corr}, the interference effects can be stronger or weaker, resulting in the non-monotonic shape of correlation function as illustrated in Fig. 3.

In contrast to the conventional reflectometer, the imaging system with two lenses shows a high correlation at the focus distance even for the large antenna-wheel separation of L = 100 cm. In contrast to the imaging system with two lenses, the one-lens system exhibits poor correlations at the focus distance for all k_{corr} values since the image plane for the one-lens system is located far from the focal plane.

The field measured in the focal plane of a lens represents the Fourier transform of an image, rather than an image itself [4]. That is why for the confocal two-lenses system the image of the reflected field is always created in the focal plane behind the lenses.

In summary, a numerical comparison of the conventional and imaging reflectometry systems was presented. Simulations revealed the ability of the two-lenses imaging system to obtain high correlation between the reflectometer signal phase fluctuations and the shape of the corrugation for the receiver location far from the target, where the conventional reflectometer signal phase is strongly distorted by interference effects.

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