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# Full Wave Modeling of Doppler Backscattering from Filaments

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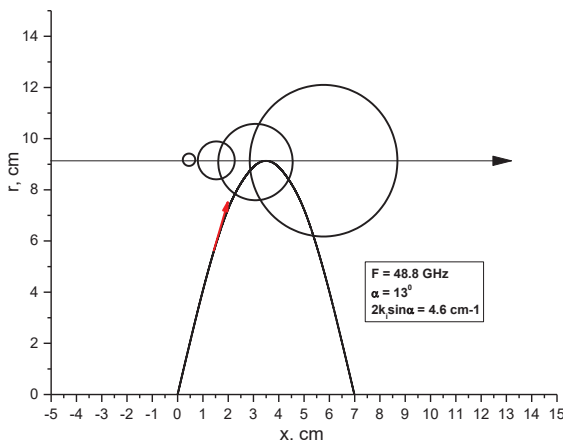
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**Abstract.** Modeling of Doppler backscattering from filaments was carried out using finite-difference time-domain code IPF-FD3D in slab geometry. In the simulation artificial filament-like perturbations were used, the parameters of which varied over a wide range. Modeling DBS signal was focused on the identification of the influence of the amplitude of the filament and its size on the DBS. first,

It is recognized that the filaments have a significant effect on the anomalous energy and particle transport in the tokamak periphery [1, 2]. They are actively investigated using various diagnostics in this regard. Recently three studies of filaments using the Doppler backscattering (DBS) method have been performed in Globus-M [3, 4] and ASDEX-Upgrade [5, 6]. The results of backscattering from filaments can be easily interpreted within the framework of the linear backscattering or Born approximation. However, the description of the experimental data under the transition from linear to non-linear backscattering is a rather complicated task that could be solved with the help of full-wave simulations.

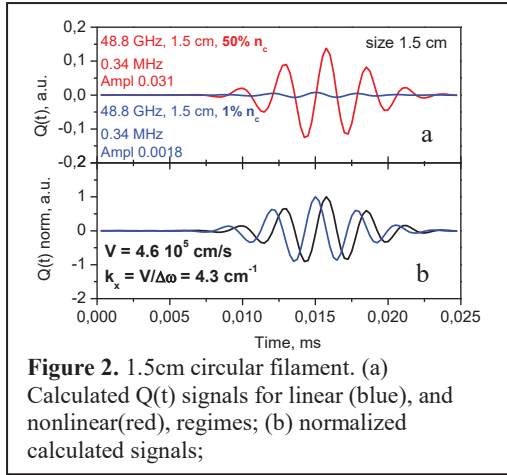


**Figure 1** Ray-tracing for 48GHz and filament cross-section.

propagation. Gaussian beam with flat wave front in the antenna mouth. This dependency of the IQ (in-phase (I) and

Our simulation was carried out using finite-difference time-domain 2D code IPF-FD3D in slab geometry [7]. We did not resort to using well-known non-linear MHD codes to determine filament parameters. In the simulation artificially created filament-like perturbations were used, the parameters of which varied over a wide range. Modeling DBS signal was focused on the identification of the influence of the amplitude of the filament and its size on the shape and size of the DBS output signal. The filament amplitudes with a Gaussian cross-section were varied from 0.1% upto 150% of density at cut off of the probing wave. The parameters of the computations are as following: antenna tilt angle  $\alpha = 13^\circ$ , antenna horn mouth 5,5 cm. Computations have been carried out for the frequencies 16GHz, 24 GHz, 32GHz, 40GHz, 48GHz, 56GHz, 64GHz of O-mode

quadrature (Q) detector signals was obtained for various filament positions in relation to the incident beam cut off.



**Figure 2.** 1.5cm circular filament. (a) Calculated  $Q(t)$  signals for linear (blue), and nonlinear (red), regimes; (b) normalized calculated signals;

Plasma density profile close to linear used for the calculations with  $n = 5.6 \cdot 10^{19} \text{ cm}^{-3}$  at  $r = 15 \text{ cm}$  and  $n = 0$  at  $r = 0 \text{ cm}$ . The filament moves in poloidal direction at fixed radius  $r = 9.2 \text{ cm}$ . The main geometrical parameters are shown schematically in the Fig.1.

The most interesting result relates to the case when the filament with a diameter of  $\pi/2k_i \cdot \sin\alpha$  moves along the cutoff (See Fig.1) (Here:  $k_i$  is free space wave number of probing beam). Remarkable that with an increase in the filament amplitude from 0.1% to 100% of the critical density, the signals of the IQ detector retain approximately the same with the waveform and duration of bursts of quasi-coherent fluctuations (BQFs). Figure 2 shows an example of the simulation for the both linear and non-linear cases. The result obtained indicates that even with strongly nonlinear scattering, the response of the IQ detector is represented as BQF. It is important that similar bursts were observed on both tokamaks, despite the possible significant

difference in the amplitude of the filaments. [1-4]. While maintaining the shape similarity, the amplitude of the signals nonlinearly increases with filament amplitude increasing. As soon as the signal amplitude is usually measured in experiment in arbitrary units it is not possible to determine the real degree of nonlinearity of the process of Doppler backscattering from filaments.

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