THE BROADENING OF SPECTRUM OF OSCILLATIONS EXCITED BY ACTIVE ANTENNA ARRAY

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The plasma was heated by two active antenna arrays. The noise generator based on the nonlinear feedback scheme was used as a master oscillator. Similar measurements were made with the pulse generators used as master oscillator. The pulse repetition frequency was up to 30 MHz.

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INTRODUCTION

The results of our experimental study are based on the technical solution described earlier [1,2]. Commonly it is clear that a charged particle during its motion along the magnetic field axis interacts with the wave field in two ways depending on particle velocity and magnetic field intensity [3].

The first way represents a Cherenkov resonance between the wave and the charged particle. It takes place when the particle velocity is equal to the wave phase velocity $V_\varphi = \omega/k$. Here ω is the wave frequency and k is the wave number [4].

Other way is a cyclotron resonance. This type of wave-particle interaction is usually observed when the wave frequency in the reference frame of the moving particle is equal to ω_B or $n\omega_B$. Where $\omega_B = eB/mc$ is an electron cyclotron frequency and $n = 1, 2, \ldots$ is an integer value, m and e are the electron mass and charge respectively and c is velocity of light. The energy transmission rate depends on two factors: the number of resonant particles and the width of resonance band in the space of phase velocities of the waves excited in plasma [5].

The system of a broadband spectrum of HF-wave excitation and introduction into plasma volume allows us to generate oscillations with the frequency band and variation range dependent on parameters of the master oscillator signal. The oscillation phases at different exciters were also controlled.

An active antenna array is a multi-element system where each element represents an oscillator coupled with an active element (generator, amplifier). For all of them the using of feeder path on a high power level is excluded. The phased array represents an antenna system composed of elements with independent phase driving.

In our case the phased array is used for generating the broadband oscillations which then would be introduced into plasma to excite the waves in a broad frequency band. For the oscillations frequency band broadening a non-sinusoidal oscillations form was used. Another way of the excited oscillations spectrum broadening is using different type of modulation. It is also effective to use a consecutive switching of a single oscillators and arrays.

A short distance between the plasma and the array components is a necessary condition of the phase array operating with the plasma load. Thus active elements of the phased array must endure a strong electromagnetic load. Besides, the amplifying elements must be capable to operate in vacuum and in a strong magnetic field. All of these requirements were taken into account during the phased array development.

EXPERIMENTAL SETUP

The interaction between the wave and the particle was studied using the experimental setup (Fig. 1.) which represented a vacuum chamber placed into a longitudinal magnetic field. The field intensity was varying from 100 to 2000 Oe. Its longitudinal distribution represented the configuration of double mirror trap with the corresponding mirror ratio 1/4.

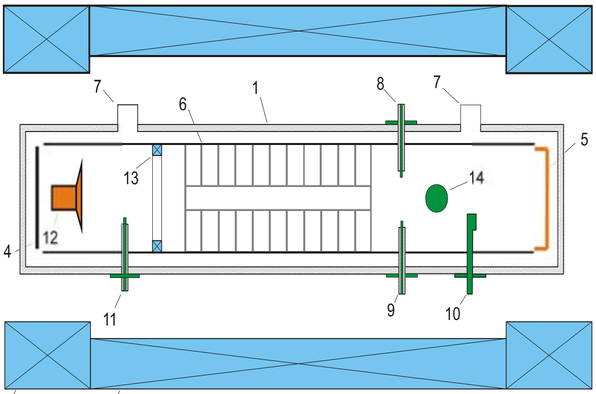

Fig. 1. Schematic of the experimental setup.
1– vacuum chamber; 2, 3 – magnetic field coils;
4 – collector; 5 – plasma source; 6 – drift tube;
7 – vacuum pumping; 8,11 – Langmuir probes;
9 – magnetic probe; 10, 12 – electrostatic analyzers;
13 – Rogovsky coil; 14 – movable electrostatic probes

The pressure in the chamber was held in the range between 10^{-4} and 10^{-6} Torr. The phase array was placed in the central area of the vacuum chamber. It was used as a source of the broadband electromagnetic oscillations. The plasma was created by coaxial HF-source placed at the one of the drift tube ends. The plasma was obtained by introducing HF-power at the electron-cyclotron frequency into the working gas volume. The source was powered by 600 W magnetron which worked continuously at the frequency f = 2.45 GHz. The density of created plasma was n = (2…5)·10^{10} cm^{-3} and the temperature T= 10 eV. The diameter of the plasma column cross-section was D = 8 cm and the length was L = 150 cm.

A number of HF-field and plasma diagnostics were used. Two electromagnetic probes of different length were placed on a mobile carriage for measuring the HF-oscillations distribution along the magnetic field axis. Two double probes were located at the lateral windows of the vacuum chamber.

ACTIVE PHASED ARRAY

The phased array represents a number of loops which cover the plasma column [4]. The system consists of two sections. Each section contains four oscillators. The length of each section is 20 cm. To avoid a contact with the plasma the sections were isolated from the plasma volume by cooled limiters. Studied configuration has an external diameter 15 cm while internal diameter was 7.5 cm the antenna loop diameter was 8.5 cm.

A power amplifier (PA) coupled with the loop (oscillator) represents a fundamental part of the array. These amplifiers may be used as broadband amplifiers or high-powered pulse generators. The PA was driven by a master oscillator which could be a sinusoidal oscillator, a noise generator, an impact generator or a pulse generator.

The phased array oscillators were capable to operate in several modes.

1. Co-phased mode. The oscillators array works as a single generator.

2. Consecutive mode. The oscillators are switched on by turn.

3. Group-consecutive mode. Oscillators are separated in different groups which are switched on consecutively.

PA was connected with external devices by feeder, power circuit, power amplifiers control circuits, and waveform control circuits.

RF - POWER INTRODUCTION MODES

The RF power introduction was carried out in two different modes. In the first case we used a simple noise generator to create a master oscillator signal. Such signals were applied to both of the phased antenna arrays without any sufficient temporal delays.

In the second case two different pulse generators were used as master oscillators. The output of each generator was directed to one of the antenna arrays. The temporal delay between the signals applied to the different antenna arrays was t = 4…7 ns.

The results of RF – power introduction into plasma using the noise generator as a master oscillator are depicted by the light grey curves, Fig. 2. Similar dependences for the case of using pulse generator as a master oscillator are shown by the dark grey lines.

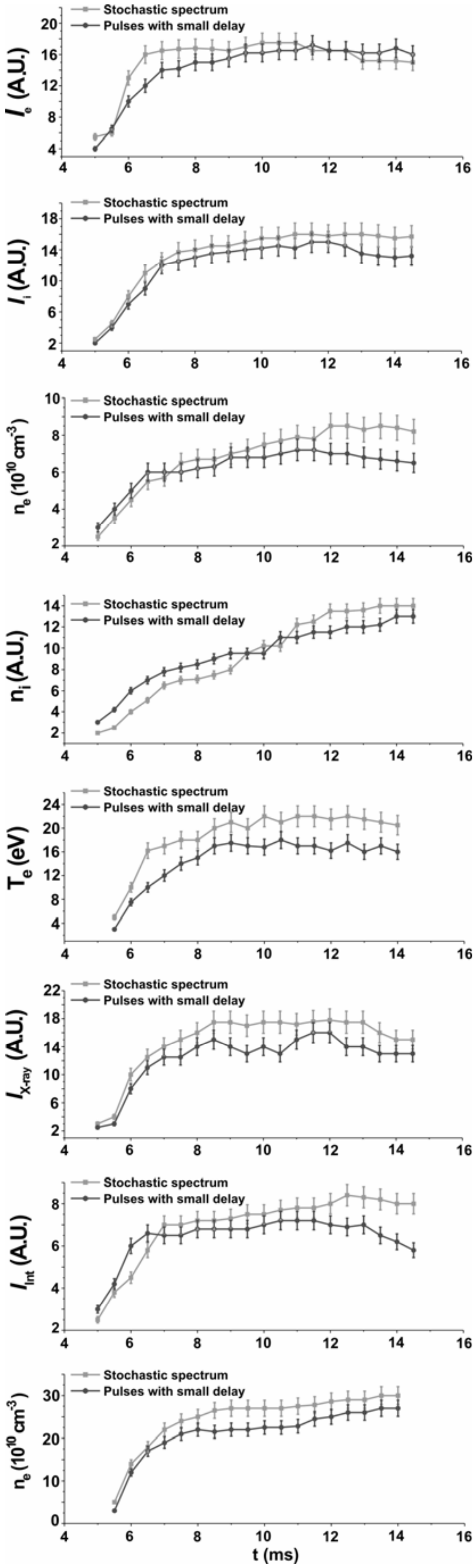

Fig. 2. Temporal dependences of electron current (I_e), ion current (I_i), electron density (n_e), ion density (n_i), X-ray radiation intensity (I_{X-RAY}), integral luminescence (I_{int}), electron density (n_e), electron temperature (T_e) for two different types of master oscillator

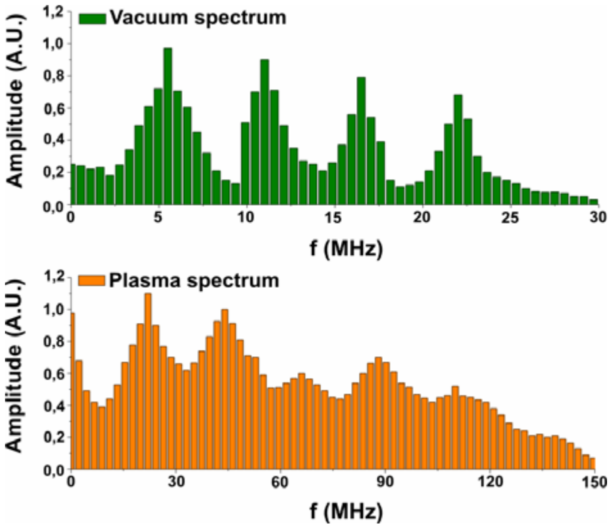

Fig. 3. The frequency spectrums measured in the experimental setup main volume during the RF power introduction from the phased antenna array with the noise generator used as a master oscillator

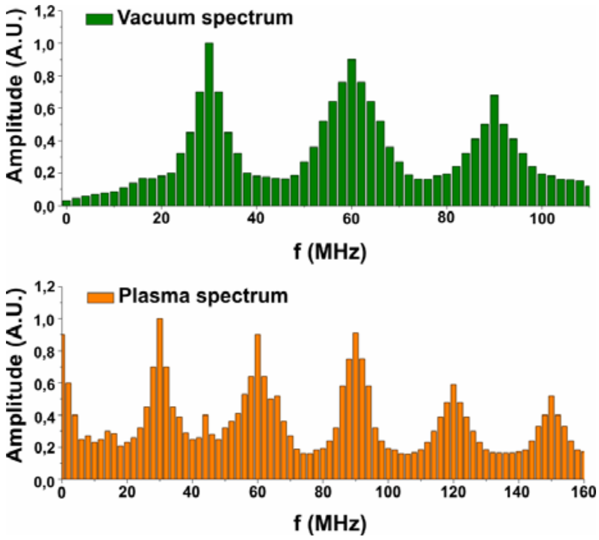

Fig. 4. The frequency spectrums measured in the experimental setup main volume during the RF power introduction from the phased antenna array with a set of pulse generators used as master oscillators

In both figures (Figs. 3, 4.) Green bars depict the case when the RF power is introduced into a vacuum volume. Orange bars show the spectrum excited by the RF pumping in the externally created plasma (noise generator used as a master oscillator) Fig. 3.

CONCLUSIONS

The frequency spectrum broadening during the interaction of broadband oscillations with the externally created plasma may be explained by excitation of the parametric instability.

This conclusion was made after observation of a threshold excitation of the oscillations and large number of frequency harmonics.

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РАСШИРЕНИЕ СПЕКТРА КОЛЕБАНИЙ, ВОЗБУЖДЕННЫХ ФАЗИРОВАННОЙ АКТИВНОЙ АНТЕННОЙ РЕШЕТКОЙ

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Плазма нагревалась двумя активными фазированными антенными решетками. В качестве задающего использовался генератор шумов, построенный на основе схемы с нелинейной обратной связью. Аналогичные измерения проводились с использованием в качестве задающего генератора коротких импульсов. Частота повторения импульсов достигала 30 МГц.

РОЗШИРЕННЯ СПЕКТРА КОЛИВАНЬ, ЗБУДЖЕНИХ ФАЗОВАННОЮ АКТИВНОЮ АНТЕННОЮ РЕШІТКОЮ

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Плазма нагрівалася за допомогою двох активних фазованих антенних решіток. У якості задаючого використовувався генератор шуму, побудований на базі схеми із нелінійним зворотним зв’язком. Аналогічні вимірювання проводилися із використанням генератора коротких імпульсів, у якості джерела задаючого сигналу. Частота повторення імпульсів сягала 30 МГц.