PLASMA ELECTRONICS

USING OF PERFECTLY MATCHED LAYER (PML) IN COMPUTER SIMULATION OF THE HIGH-POWER RELATIVISTIC PLASMA MICROWAVE AMPLIFIER

I.L. Bogdankevich, A.A. Rukhadze, V.P. Tarakanov*
Prokhorov's General Physics Institute RAS, Moscow, Russia, bira@fpl.gpi.ru;
****High-energy density research Center RAS, Moscow, Russia, karat@tarak.msk.su***

Computer simulation of the relativistic plasma microwave amplifier was made by using code KARAT. A pure amplification regime (without accompanying generation) was achieved in such amplifier in the experiment [1]. The simulation system was made nearly the same experimental setup. The main feature of this model is a microwave absorber.

PACS: 52.40.Mj

STATEMENT OF THE SIMULATION PROBLEM

Realignment from the amplifier regime to the generation one is a serious task both to the computer simulation and to the experimental study of the plasma relativistic microwave amplifier. The reason is that the big gain value, even though there is a small positive feedback, transfers the system to the generation regime. The microwave absorber is loaded into the system to suppress this effect. Experimental device and study of the microwave amplifier was described in the paper [1]. According to [1] the regime of pure amplification (without accompanying generation) of monochromatic microwave signal in a plasma relativistic microwave amplifier was achieved for the first time in experiment at frequencies of both 9.1 and 13 GHz. Some results of the experiment correlate qualitative well with linear and nonlinear theory of the microwave amplifier [2]. But as previously noted in [1], the presence of the microwave absorber, reflections from the waveguide ends, and the pulsed character of the process lead to an appreciable discrepancy between the experimental and calculated results. This means that is necessary to carry out calculations using a more complicated model. Reflection of electromagnetic waves from the junction between a waveguide filled with tubular plasma and a vacuum coaxial waveguide was considered in [3]. But in [3] was not taken into account electron beam and thereby was not analyzed the operation of the plasma microwave amplifier.

In our work was used two-dimensional axisymmetric version of the KARAT particle-in-cell electromagnetic code [4]. A computer simulation schematic is shown in Fig.1. The code solved a set of Maxwell's equations with boundary conditions for metal on waveguide surfaces, the relativistic equations of motion for beam electrons and used the linear model for calculating plasma current. The electron beam was simulated by the particle-in-cell method. The particles were injected from the left boundary. Coaxial, which disposed in the left part of the system, makes possible injecting into a drift tube a TEM-wave with fixed frequency f_0 and power (frequency range from 5 to 15 GHz, average power 25 kW). Metallic waveguide radius is R = 2 cm, annular plasma R_{pl} = 0.8-1 cm, beam R_b = 0.5-0.6 cm and R_b = 0.7-0.8cm, I_{beam} = 1 kA, $\gamma = 2$.

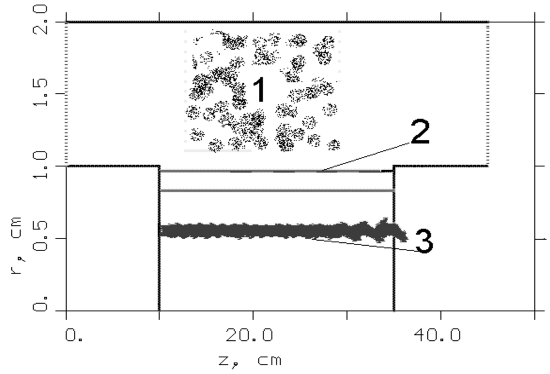

Fig.1. A computer simulation schematic. 1 –absorbed layer , 2 – plasma, 3 – beam

The system was embedded in a finite uniform longitudinal magnetic field B. Length of the plasma-beam interaction area was chosen (L = 36 cm) as a result of the computer simulation to suppress generation at Cherenkov resonance frequencies. A substantial feature of this model is a microwave absorber, located in area 1, on Fig.1. In this work was applied a media, where were realized absorbing boundary conditions according to Berenger's Perfect Matched Layer [5]. This absorber may be considered as an anisotropic active material.

SIMULATION RESULTS

The amplifier output power dependence on the input wave frequency at difference plasma density values is shown on fig.2. Two graphics correspond to two values of the beam radius. Up – the gap between beam and plasma is 2 mm, down – the gap is zero. This geometric factor affects on the parameter value of the plasma-beam waves connection [2]. There is an essential difference for gain efficiency in these two cases. There is a relative narrow gain frequency band for maximum gain efficiency (see grey squares on down graphic of fig.2). The efficiency decreases at the magnification of plasma density, but gain frequency band expands. Two gain regimes are in keeping with two graphics on the fig.2. Linear regime (up graphic) is in line with the week connection, nonlinear regime is in line (down), with the strong connection. Two phase portraits for mentioned regimes are shown on fig.3. Two values of the input wave frequency (9 and 13 GHz) were used in experiment [1].

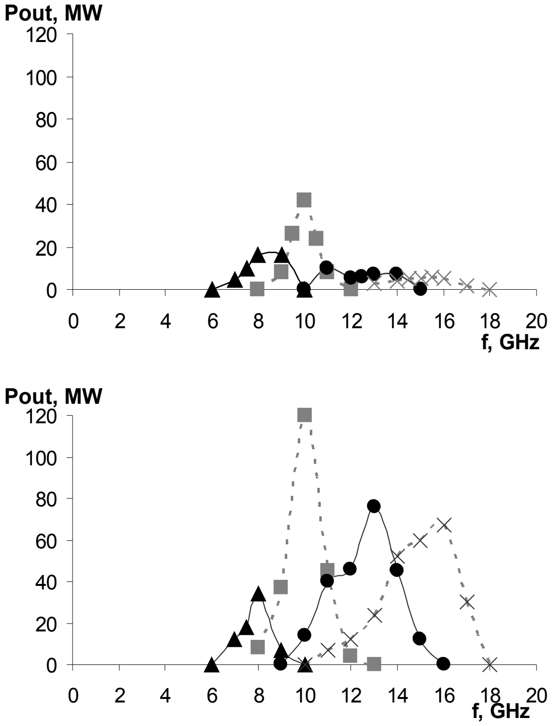

Fig.2. Amplifier output power dependence on the input wave frequency at difference plasma density values: triangles – 5 10^{12}, grey squares – 7 10^{12}, circles – 1.1 10^{13}. crosses – 1.3 10^{13}

The gain efficiency dependence on the plasma density was calculated for these two frequencies. Graphics for

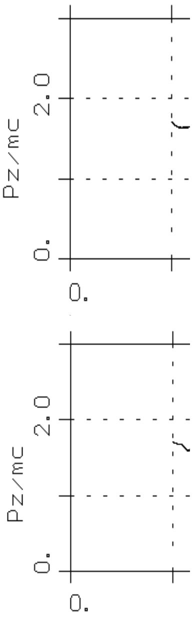

Fig.3. Elect

for week com

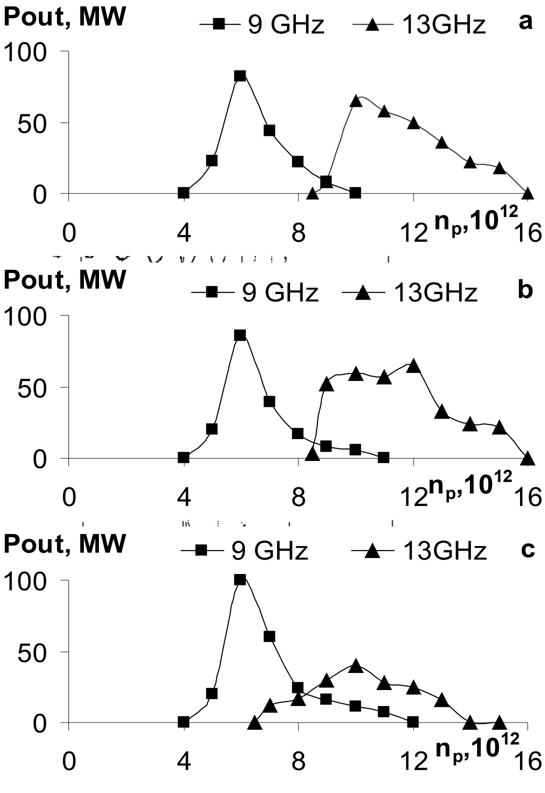

Fig.5.Functioning efficiency dependence of the amplifier on the magnetic induction value:
a – 1.5 T, b = 1T, c = 0.6 T

two beam radiuses are shown on the fig.4. Curves are presented on the fig.4 were made for B = 3 T. From these graphics we notice that there is no area of plasma density values, where the same gain efficiency for both fixed frequencies may be detected.

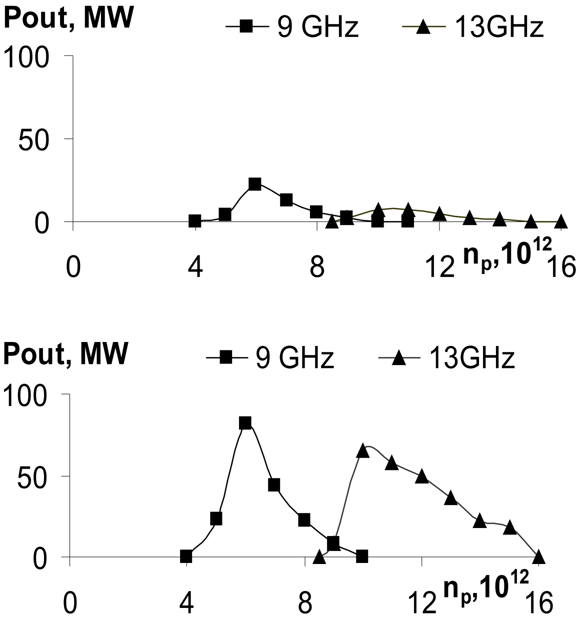

Fig.4. Amplifier output power dependence on the plasma density for two fixed frequencies of the input wave: up – week connection, down – strong one

The impact of the uniform magnetic field value upon the plasma microwave amplifier functioning was considered in this work. The computer simulation was made for four values of the uniform magnetic field B = 3, 1.5, 1 and 0.6 T. The impact of variation B upon the plasma microwave amplifier functioning was not observed for week connection between beam and plasma. For strong connection, simulation results are presented on fig.5 a,b,c for B =1.5, 1, 0.6 T accordingly. From graphics b and c we notice that there is an area of plasma densities, where the gain for both fixed frequencies (9 and 13 GHz) may be detected quite well. The fact of a common area existing has a qualitative agreement with experimental results [1]. Gain efficiency decreases as the uniform magnetic field is reduced. It is particularly clear noticed for frequency 13 GHz. Now we have not a detailed physical model of the amplifier at finite uniform magnetic field using in experiments [1]. But at the finite magnetic field the new resonances and new mechanisms of beam-plasma interaction arise. They are known as normal and anomalous Doppler effects.

It is possible that the competition between Cherenkov and Doppler effects can influence on the Cherenkov instability. This task was considered in the report by M.Kuzelev and A.Rukhadze “Influences of Normal and Anomalous Doppler Effects On Development of a Beam-Plasma Instability”.

CONCLUSIONS

A special type of the anisotropic active media was used for the first time to simulate numerically the relativistic plasma microwave amplifier with absorber.

From mentioned above results may be done following conclusions.

1. In the course of the computer simulation parameters of the absorber were sorted out well to ensure a stable gain regime in a broad frequency range by the variation of the plasma density value.
2. A relatively big gain at frequencies 9 and 13 GHz was observed in a case of the strong plasma-beam connection. It takes place when the gap between electron beam and annular plasma is small. The gain achieved the level 30 dB.
3. Gain efficiency weekly decreases as the uniform magnetic field is reduced. It is particularly clear noticed at frequency 13 GHz and values of B ≤ 1 T.

ACKNOWLEDGEMENTS

The work was supported by Government of Russia, program of the state support of unique scientific research and experimental installations in Russia (reg. # 01-04); Russian Academy of Sciences, project "Broadband Relativistic Cherenkov Plasma Maser“, the Russian Foundation for Basic Research (#01-02-17265)

REFERENCES

1. A.V. Ponomarev and P.S.Srelkov // *Plasma Physics Reports.* 2004, 30 (1), p.62-68, .
2. M.V. Kuzelev, O.T. Loza, A.A. Rukhadze et al. // *Plasma Physics Reports.* 2001, 27 (8), p.710-733.
3. I.N.Kartashov, M.A.Krasil’nikov and M.V.Kuzelev // *Journal of Communications Technology and Electronics.* 1999, 44 (12), p.1502-1509.
4. V.P.Tarakanov. *User’s Manual for Code KARAT.* Springfield, VA: Berkley Research Associates Inc. 1992.
5. J.-P.Berenger // *J. Comput. Phys*. Oct., 1994, 114(2), p.185-200.

ИСПОЛЬЗОВАНИЕ ПОГЛОЩАЮЩЕГО СЛОЯ В ЧИСЛЕННОМ МОДЕЛИРОВАНИИ СИЛЬНОТОЧНОГО РЕЛЯТИВИСТСКОГО ПЛАЗМЕННОГО МИКРОВОЛНОВОГО УСИЛИТЕЛЯ

И.Л. Богданкевич, А.А. Рухадзе, В.П. Тараканов

---

[1] The work was supported by
Government of Russia, program of the state support of unique scientific research and experimental installations in Russia (reg. # 01-04); Russian Academy of Sciences, project "Broadband Relativistic Cherenkov Plasma Maser“, the Russian Foundation for Basic Research (#01-02-17265)

С помощью кода КАРАТ [4,5] нам удалось численно промоделировать усилитель, используя поглотитель в виде модельной среды с заданными параметрами. Путем изменения параметров поглощающей среды и коэффициента отражения выходного зеркала [3], удалось подобрать оптимальный режим усиления микроволнового излучения на заданной частоте. В широком диапазоне изменения указанных параметров достигнуто усиление в 30 дБ.

ВИКОРИСТАННЯ ПОГЛИНАЮЧОГО ШАРУ В ЧИСЕЛЬНОМУ МОДЕЛЮВАННІ ПОТУЖНОСТРУМОВОГО РЕЛЯТИВІСТСЬКОГО ПЛАЗМОВОГО МІКРОХВИЛЬОВОГО ПІДСИЛЮВАЧА

І.Л. Богданкевич, А.А. Рухадзе, В.П. Тараканов

За допомогою коду КАРАТ [4,5] нам удалося чисельно промоделювати підсилювач, використовуючи поглинач у виді модельного середовища з заданими параметрами. Шляхом зміни параметрів поглинаючого середовища і коефіцієнта відображення вихідного дзеркала [3], удалося підібрати оптимальний режим посилення мікрохвильового випромінювання на заданій частоті. У широкому діапазоні зміни зазначених параметрів досягнуте посилення в 30 дБ.