UDC 621.385.6

MODE INTERACTION FOR RANDOM SIGNAL GENERATION IN MM-WAVEBAND VACUUM OSCILLATORS

E. M. KHUTORYAN

We consider transformation of single frequency oscillations to multi-frequency and to the chaotic ones in Smith-Purcell radiation (SPR) multiplier. It consists of grating with upper mirror that enables both BWO and diffraction radiation oscillator (DRO) modes excitation. We consider the case when fundamental frequency oscillation corresponds to backward wave oscillator mode. The SPR condition holds for nth harmonic (3rd in our case). When operating-to-starting current ratio exceeds unit value for both modes the auto-modulation process takes place, which leads to generation of oscillations with multifrequency spectrum. The reason for this is BWO and DRO modes interaction. When operating current exceeds starting one many times both for BWO and DRO mode the oscillation spectrum becomes a continuous one. The spectrum behavior has been studied for various system parameters such as electron beam current, grating length, OR quality factor, etc.

Keywords: Backward wave oscillator, Diffraction radiation oscillator, Smith-Purcell radiation multiplier, mode interaction, stochastic oscillations.

INTRODUCTION

The electron vacuum oscillators can generate stochastic oscillations when electron beam (EB) is overbunched and there is time delay of wave propagation. One of the most known examples are backward wave oscillator (BWO) and reflection diffraction radiation oscillator (R-DRO) [1, 2]. Also reason for stochastic oscillation can be the mode interaction in overmoded resonant devices such as gyrotron, resonant BWO, DRO, etc. Mode interaction is possible also for different types of feedback. In [3] the mode competition between BWO and DRO modes has been studied both theoretically and experimentally. It was shown that for moderate operating current single frequency oscillatory mode is established: for low EB velocity BWO when coupling impedance is rather low the DRO oscillations are excited; for higher EB velocities BWO oscillations occur. Later experimentally was shown possibility of BWO and DRO simultaneous oscillations [4]. It can lead to stochastic oscillatory mode. Another case of BWO and DRO modes interaction is Smith-Purcell multiplier [5]. In this case BWO mode self-excites on the fundamental frequency and SPR condition holds for n^{th} harmonic. If it coincides with the open resonator resonant frequency the DRO mode is excited [6, 7]. Here we consider the case when operating-to-starting current ratio exceeds unit value for both modes that can lead to generation of EM oscillations with continuous spectrum.

THEORY

As it is known, for BWO mode the phase shift φ over grating period l is between π and 2π. If the EB velocity is v then oscillation frequency will be close to $f = vl/\varphi$. The nth harmonic frequency is nvl/φ and $n\varphi = 2\pi m$. This gives certain values of phase shift φ for SPR. Since BWO wavelength approximately equals quarter of grating depth λ~h/4 the effective SPR takes place for odd harmonics. Let's consider the case when $n = 3$ and $m = 2$ (Fig. 1). Then BWO electric field may be represented as superposition of forward and backward wave:

$$\vec{E}_{BWO} = C^{+}(y,t)\vec{E}_{p}(y,z,k)e^{i(ky-\omega t)} + \\ +C^{-}(y,t)\vec{E}_{-p}(y,z,k)e^{i(-ky-\omega t)}$$

whose amplitudes have been governed by following excitation equations:

$$\begin{cases} \dfrac{1}{v_{gr}}\dfrac{\partial C^{-}}{\partial t} - \dfrac{\partial C^{-}}{\partial y} + \gamma C^{-} = \dfrac{1}{\tilde{N}_{-p}}\displaystyle\int_{S}\overline{\vec{j}_1(t)\vec{E}_p e^{i\omega t}}dS \\ \dfrac{1}{v_{gr}}\dfrac{\partial C^{+}}{\partial t} + \dfrac{\partial C^{+}}{\partial y} + \gamma C^{+} = 0 \\ C^{+}(0,t) = R_1 C^{-}(0,t) \\ C^{-}(L,t) = R_2 C^{+}(L,t)e^{i2kL} \end{cases} \quad (1)$$

The vortex field DRO of high Q cavity can be represented as an expansion by cavity eigenmodes:

$$\vec{E}_{DRO} = \sum_{m} C_m(t)\vec{E}_m(y,z)e^{i(4\pi y/l - 3\omega t)}$$

where $\vec{E}_m(r)$ is electric field of the cavity eigenmode. If resonator is not overmoded the only single DRO mode is assumed to be excited. Then, in a weakly non-stationary approximation the equation for the DRO complex mode amplitudes becomes

$$-\frac{dC}{dt} + i(3\omega - \omega_{DRO})C = \frac{1}{N_m}\int_{V}\overline{\vec{j}_3(r,t)\vec{E}_m(r)e^{i3\omega t}}dV, \quad (2)$$

where $N_m = \dfrac{1}{4\pi}\displaystyle\int_{V}\varepsilon\vec{E}_m^2 dV$ is the mth mode norm, $\vec{j}_{1,3}$ is the current density of first and third harmonic, respectively, which are to be found from the motion equation.

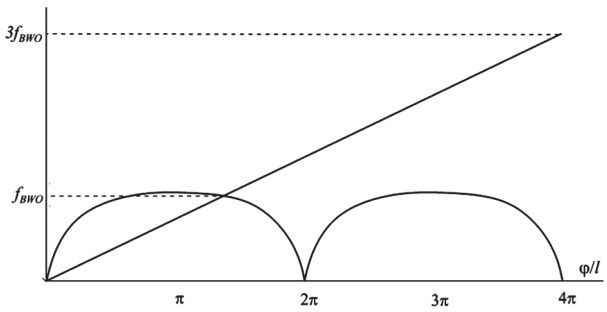

Fig. 1. Dispersion of BWO

RESULTS

Solving the equations (1) and (2) together with EB motion equation we obtain time dependence of BWO and DRO amplitudes. Let's note that for case [3, 4] when $\omega_{DRO} \neq n\omega$ the solution for single frequency regime occurs when $C^{\pm} \neq 0$, $C = 0$ or $C^{\pm} = 0$, $C \neq 0$. At SPR multiplier $\omega_{DRO} = n\omega$ both amplitude non-equal to zero. Therefore for arbitrary frequency ratio the following regimes have been observed [4]: 1) single frequency; 2) two-frequency with different frequency steepness: 3) BWO frequency spectrum enrichment due to auto-modulation; 4) stochastic mode interaction; 5) mutual mode synchronization for $f_{BWO}/f_{DRO} = 5/6$ with the same frequency steepness for both modes.

For case of SPR multiplier the parameters to be varied are resonator Q-factor, EB current, reflection factors, grating length, frequency mismatch, EB inclination angle.

Amplitude time dependences and corresponding FT for matched BWO ($R_{1,2} = 0$) have been shown in Fig. 2. EB current-to-starting one ratio for BWO equals 6 and for DRO is 2.3; frequency mismatch is 0 and Q = 200. Let's note that even for exact relation between 'cold' frequencies ($\omega_{DRO} = 3\omega$) the electron frequency shift for BWO mode results in some mismatch. Additional BWO mode automodulation (appearing additional frequencies in BWO spectrum) makes DRO dynamics much more complex. From Fig. 2 one can see that DRO automodulation is deeper than that for BWO. If frequency shift is more than DRO resonator bandwidth there is DRO mode collapse. In this case near DRO modes should be considered.

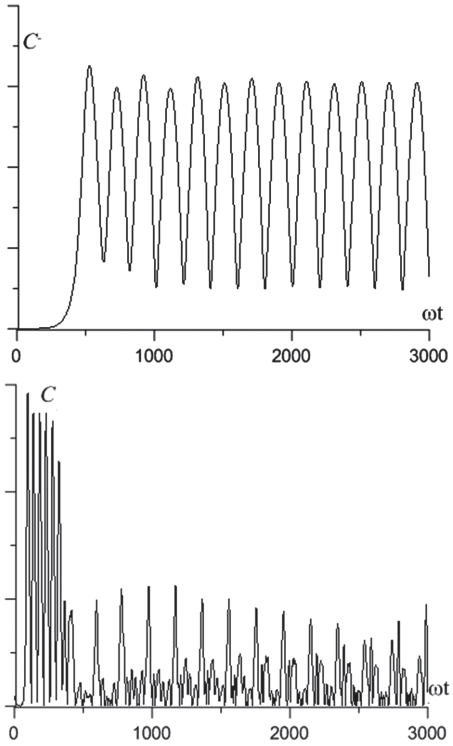

Fig. 2. Amplitudes time dependence EB current-to-starting one ratio for BWO equals 6 and for DRO is 2.3

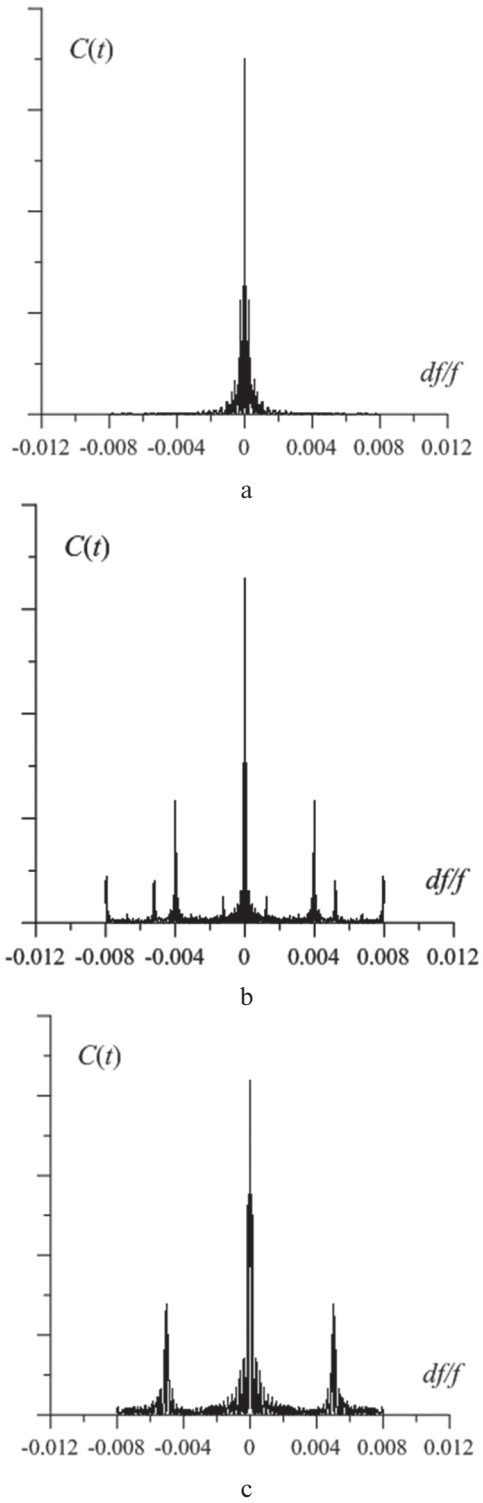

Fig. 3. DRO amplitudes FT for EB current-to-starting one ratio for DRO equals a) 0.7; b) 2; c) 3.5

FT evolution at EB current change shown in Fig.3 indicates enrichment of oscillation spectrum due to deep automodulation.

CONCLUSIONS

The mechanism for stochastic oscillation generation in SPR multiplier has been considered. It is shown that BWO and DRO modes interaction leads to deep automodulation and multifrequency spectrum and there is feasible possibility for stochastic oscillations. The variation of large quantity of both

modes parameters enables different ways of oscillation spectrum transformation.

Author would like to thank Konstantin Lukin for the suggested topic and useful discussions and suggestions.

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Manuscript received February, 22, 2013

Eduard Khutoryan received his diploma in Radiophysics & Electronics from Kharkov National University in Ukraine in 2000. Since 2000, he has been with the Institute for Radiophysics and Electronics, National Academy of Sciences of Ukraine, IRE NASU, Kharkov. He completed his Ph.D. thesis at IRE NASU in 2011. He is currently working on microwave and terahertz vacuum electron devices. He is the author/coauthor of more than 25 publications in peer-reviewed journals and conferences.

УДК 621.385.6

Взаимодействие мод в вакуумных генераторах миллиметрового диапазона для генерации случайных сигналов/ Э. М. Хуторян // Прикладная радиоэлектроника: науч.-техн. журнал. – 2013. – Том 12. – № 1. – С. 51–53.

Рассматривается преобразование одночастотных колебаний в многочастотные и хаотические в умножителе на эффекте Смита-Парселла (СП), состоящем из гребенки и верхнего зеркала и поддерживающем возбуждение режимов ЛОВ и ГДИ. Рассматривается случай возбуждения режима ЛОВ на основной гармонике. Режим излучения СП при этом наблюдается на третьей гармонике. Когда рабочий ток превышает стартовый для обоих режимов, наблюдается многочастотная генерация, причиной которой является взаимодействие мод ЛОВ и ГДИ. Когда рабочий ток намного превышает стартовый для обоих режимов, спектр колебаний становится непрерывным. Исследуется поведение спектра в зависимости от различных параметров, таких как ток, длина гребенки, добротность резонатора и т.д.

Ключевые слова: взаимодействие мод, ЛОВ, ГДИ, многочастотные колебания, высшие пространственные гармоники.

Ил. 03. Библиогр.: 07 назв.

УДК 621.385.6

Взаємодія мод у вакуумних генераторах міліметрового діапазону для генерації випадкових сигналів / Е. М. Хуторян // Прикладна радіоелектроніка: наук.-техн. журнал. – 2013. – Том 12. – № 1. – С. 51–53.

Розглянуто перетворення одночастотних коливань в багаточастотні і хаотичні в помножувачі на ефекті Сміта-Парселла (СП), що складається з гребінки і верхнього дзеркала, які підтримують збудження режимів ЛЗХ і ГДВ. Розглядається випадок збудження режиму ЛЗХ на основній гармоніці. Режим випромінювання СП при цьому спостерігається на третій гармоніці. Коли робочий струм перевищує стартовий для обох режимів, спостерігається багаточастотна генерація, причиною якої є взаємодія мод ЛЗХ і ГДВ. Коли робочий струм набагато перевищує стартовий для обох режимів, спектр коливань стає безперервним. Досліджується поведінка спектра в залежності від різних параметрів, таких як струм, довжина гребінки, добротність резонатора і т. д.

Ключові слова: взаємодія мод, ЛЗХ, ГДВ, багаточастотні коливання, вищі просторові гармоніки.

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