QUASI-HARMONIC RF OSCILLATIONS IN A GYROTROPIC NONLINEAR TRANSMISSION LINE

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The paper considers formation of quasi-monochromatic radio frequency oscillations under the influence of a short carrier-free pulse of electric current, in the transmission line of doubly connected cross-section partially filled with a magnetized ferrite. The frequencies and amplitudes of the oscillations are determined by dispersive and non-linear properties of the structure which are, in their turn, governed by the geometry and size of the line proper, and the spatial structure of the ferromagnetic material with its intrinsic dispersion. The dependences shown by the oscillation parameters in physical experiments are reproduced and analyzed via numerical simulation within models which account separately for different physical properties of the material and the structure.

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INTRODUCTION

The physical effects leading to direct conversion of short carrier-free electric pulses into radio frequency oscillations have been a subject of intense studies for quite a long time [1, 4-12]. In fact, this possibility stands out as a real achievement in the field of high power electronics, reached over the few past decades. The early work in the field, dating back to 1960s [1-3], was concentrated on excitation of electromagnetic shock waves in lumped-parameter nonlinear trans-mission lines (NLTL) and formation of pulsed waveforms with a sharp leading edge [2, 3]. Later on, the interest shifted toward studying the radio frequency oscillations that accompanied passage of the shock through the NLTL. They could be observed both in lumped parameter lines containing discrete components with some kind of nonlinear behavior, and in waveguides filled with a ferromagnetic material [4, 5, 9-11]. In the latter case it is essential that the guide's cross-section should topologically be a double connectivity object, so as to admit unipolar electric pulses. The obvious candidates are coaxial cables and planar strip lines.

In the experiments where the transmission line contained a ferrite core magnetized very nearly to saturation, the short carrier-free current pulse could give rise to quasi-monochromatic oscillations [4, 5, 9], or rather, damped sinusoidal waveforms of frequencies f_0 falling into the decimeter wave range (often between 0.3 and 6 GHz). Such signals revealed a rather small number of periods, which actually suggests a fairly broad bandwidth, $\Delta f/f_0 \approx 1$. Thus, gyromagnetic nonlinear transmission lines can be seen as a new technology to produce short radio frequency pulses of very high (megawatt level) intensity. They may prove useful for many applications with modest demands as to spectral line purity or total radiated energy, like subsurface radar or EMC test beds [7, 8]. The advantage of such systems is their ability to operate without intense particle beams or high vacuum [5, 9, 11]. Still, despite these practical achievements and continued efforts of many researchers, the underlying physics remains poorly understood. The widely shared idea concerning reasons for the appearance of the oscillations has been the impact of the magnetization vector's precession about the direction of the total d.c. magnetic field in the ferrite [4, 6, 11]. Unfortunately, this does not explain either the oscillation frequency dependence upon the line's cross-section diameter or even the frequency value itself. In this paper we are trying to summarize the better established facts concerning generation of RF oscillations in NLTLs and suggest a consistent electrodynamic vision of the principal effects.

1. WAVE PROCESSES IN THE NLTL

The coaxial structure used in our (and other) experiments, Fig.1, will be described in a cylindrical frame of reference (z,ρ,φ), where z is the coordinate along the line's axis; ρ the radial, and φ the angular coordinate. It involved two uniform lines, TL1 and TL2, at the input and output, respectively, and the NLTL partially filled with a ferrite. The cross-section sizes of all three TLs were the same, D_3 =52 mm and D_1=20 mm, which figures determined a 38 Ohm impedance for the TEM mode, and the lengths of 100 mm for TL1 and TL2, and 800 mm for NLTL.

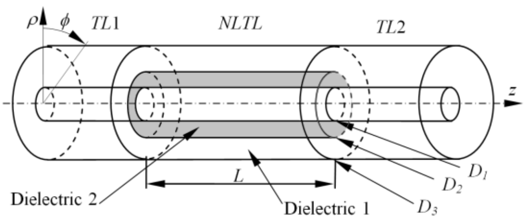

Fig. 1. Schematic of the transmission line

The TL1 and TL2 were fully filled with a [liquid] dielectric with constant parameters ε = 2.25 and μ= 1, whereas in the NLTL the filling medium occupied two layers. The outer one, $D_2/2 \le \rho \le D_3/2$, contained the same isotropic dielectric as the input line TL1, while the space $D_1/2 \le \rho \le D_2/2$ accommodated a cylindrical ferrite core with D_2 =32 mm (actually, a set of closely spaced ferrite beads). The entire structure was placed in a d.c. magnetic field $\mathbf{H_0}=\mathbf{e_z}H_0$ provided by an external solenoid. The geometric and electrical parameters of the structures described by other workers [4-6, 11] differed considerably, so to compare and interpret the reported results, the diameters D, line lengths L and the magnitudes of ε and μ could be varied in numerical simulations (see below).

The processes taking place in the system can be outlined as follows. The unipolar voltage surge fed into TL1 from an external pulse-forming source travels toward the front end of the NLTL. The axial symmetry of the entire structure suggests that all field magnitudes at $\varphi = \varphi_0+2\pi$ shall be equal to the values at $\varphi=\varphi_0$, and hence the angular dependences of the wave fields are $exp(in\varphi)$ with $n = 0, \pm 1, \pm 2$, *etc*. Since TL1 presents no structural non-uniformity or anisotropy, the 'd.c.' pulse may propagate there in the form of a dispersionless (TEM) wave where the participating spatial components are, by virtue of excitation, only two, namely E_ρ (associated with the voltage across the line conductors) and $B_\varphi=H_\varphi$ (proportionate to the current through the line). In frequency-spectrum terms, both represent continuous sets of harmonic components $\sim R(\rho,\varphi)exp(i\omega t-i\kappa z)$, so far with $\partial R/\partial\varphi=inR=0$, which all travel at the same speed. The spectrum extends from 'almost d.c.' to $1/\tau$, where τ is the pulse's rise time. (Accordingly, all frequency components obey the same linear disper-sion law $\omega=\kappa v$). The highest frequency in the set determines the 'sharpness' of the pulsed waveform edge. The lowest, of amplitude about $0.5A_0$ carries the major part of the pulse's energy (A_0 is the peak amplitude of the pulsed waveform).

Upon entering the ferrite-filled part of the line the signal can no more exist as a wave packet with a single dispersion law for all frequency components. First, because the wave mode with non-zero E_ρ and B_φ gets diffracted at the dielectric-ferrite interface (where the electric and magnetic parameters of the medium change abruptly), and hence acquires longitudinal field components E_z and B_z which the former E_ρ and B_φ are coupled to through the Maxwell equations (1),

$$\begin{cases} \varepsilon_0 \dfrac{\partial(\varepsilon E_\rho)}{\partial t} = \dfrac{1}{\rho}\dfrac{\partial H_z}{\partial\varphi} - \dfrac{\partial H_\varphi}{\partial z} \\ \varepsilon_0 \dfrac{\partial(\varepsilon E_z)}{\partial t} = \dfrac{1}{\rho}\left[\dfrac{\partial(\rho H_\varphi)}{\partial\rho} - \dfrac{\partial H_\rho}{\partial\varphi}\right] \\ \mu_0 \dfrac{\partial B_\varphi}{\partial t} = \dfrac{\partial E_z}{\partial\rho} - \dfrac{\partial E_\rho}{\partial z} \end{cases} \quad \begin{cases} \mu_0 \dfrac{\partial}{\partial t} B_\rho = \dfrac{\partial E_\varphi}{\partial z} - \dfrac{1}{\rho}\dfrac{\partial E_z}{\partial\varphi} \\ \mu_0 \dfrac{\partial B_z}{\partial t} = \dfrac{1}{\rho}\dfrac{\partial E_\rho}{\partial\varphi} - \dfrac{1}{\rho}\left[\dfrac{\partial(\rho E_\varphi)}{\partial\rho}\right] \\ \varepsilon_0 \dfrac{\partial(\varepsilon E_\varphi)}{\partial t} = \dfrac{\partial H_\rho}{\partial z} - \dfrac{\partial H_z}{\partial\rho} \end{cases} . \qquad (1)$$

The $n=0$ solution is not the only one excited here. The wave modes with $|n| \geq 1$ possess different, often complex dispersion laws. The TEM ($n=0$) wave itself transforms into a TM mode with three spatial components, E_ρ, B_φ, and E_z, and reveals a slightly nonlinear dispersion law, therefore being sometimes known as a 'quasi-TEM' mode.

The magnetic induction **B** in the ferrite is $\mathbf{B}=\mu_0(\mathbf{H}+\mathbf{M})$, where **M** is the magnetization vector. The ferromagnet that was pre-magnetized to $\mathbf{M_0}=\mathbf{e}_z M_z$ by the d.c. bias field $\mathbf{H_0}$ now gets re-magnetized in the perpendicular field $\mathbf{e}_\varphi H_\varphi$ which is carried by the current pulse, $H_\varphi=h_\varphi(t)$. Accordingly, the **M**-vector assumes components oriented in the ρ-, φ-, and z-directions. The variations of M_ρ and M_φ with time represent the precession motion of **M** around the direction of $\mathbf{M_0}$. The dynamics of variations in **M** can be described within some version of the Landau–Lifschitz (L-L) equation [13], *e.g.*, the L-L-Gilbert form,

$$\partial\mathbf{M}/dt = -\gamma\mu_0[\mathbf{M}\times\mathbf{H}] - \gamma\alpha\, \mu_0/M_s\cdot[\mathbf{M}\times[\mathbf{M}\times\mathbf{H}]], \qquad (2)$$

where $\gamma = 2.8\cdot 10^{10}$ Hz/T is the gyromagnetic ratio and **H** the total magnetic field in the medium. It includes the static field H_0 and the time-dependent components $\mathbf{h}(t)$. When calculated from the Maxwell equations with due account, via boundary conditions, of the geometry and sizes of the NLTL's structural elements, the **H** vector in (2) also includes the so called demagnetizing factors [13]. Now, $\alpha < 1$ is a phenomenological parameter of this macroscopic equation, accounting for magnetic relaxation effects.

As can be seen from (2), the **B = B(H)** relation is (*a*) nonlinear and (*b*) non-scalar (reflecting anisotropy of the medium). Qualitatively, the effects of magnetic nonlinearity can be described in two ways:

1. Considering an 'effective magnetic permeability' of the ferrite, $\mu=1+M(H)/H$, we see it to be dependent on the magnetic field strength. Accordingly, the propagation velocity $v = c(\varepsilon\mu)^{-1/2}$ of the pulsed wave becomes dependent on the amplitude of H_φ (*i.e*., current amplitude). As a result, the higher-amplitude pulse components are in advance of the lower-amplitude components, thus sharpening the front edge and provoking shock formation. (Of course, this is a rather simplified treatment, as the **B=B(H)** relation is anisotropic and the refractive index c/v can hardly be associated with any scalar 'effective μ').

2. Looking at the pulse propagation process from frequency domain positions, effects of nonlinearity are understood as generation of higher-order harmonics by each frequency component in the continuous spectrum of the pulse. As long as they all move at velocities that remain close to the pulse's group velocity, we observe pulse edge sharpening. When some of the higher frequency components get close to and beyond the cut-off frequency of a dispersive TM or TE mode supported by the line, that mode may be excited and seen as a decaying sine wave.

The linear in **H** solution to the L-L-G+Maxwell equation set that describes the magnetostatic wave in the ferrite also looks like a decaying sine wave, which has led many writers to believe that the oscillations were associated exclusively with precession of the magnetization vector. Meanwhile, the frequency of magnetic moment precession is not the only characteristic frequency in the structure. The NLTL, as a line of finite-sized cross-section (and containing a layered insert at that) exhibits many characteristic frequencies and suggests a variety of dispersion laws for the electromagnetic modes that might be excited. The magnitudes determining the precession frequency are $\omega_0 = \mu_0\gamma H_0$ and $\omega_M = \mu_0\gamma M_s$ (where M_s is the saturated level of magnetization). In our experiments, as well as in [6] these magnitudes lay between 1 GHz and about $\omega_M = 10$ GHz, while the oscillations recorded showed frequencies between 0.9 and 6 GHz. Note that ω_0 and ω_M stayed constant in every specific experiment, whereas the transverse magnetic field H_φ changed noticeably over the duration of the current pulse. The numerical experiments performed with 'triangular' pulse waveforms (below, Figs. 2, 3) are in this respect of special interest. Throughout the trailing edge of large extension the magnitude of H_φ changes by a factor greater than10, while the RF oscillation frequency never varies by more than 15 or 25 %. This small amount of frequency variations, compared with the greatly changing pulse amplitude, apparently suggests an equally low significance of the magnetic state of the medium, *i.e.* of magnetization dynamics. Then we have to admit that the oscillation frequency is not (at least, not always) related to the precession frequency.

As an alternative, consider the dependences upon sizes of the structural elements. The great many experiments with nonlinear TLs of different outer diameters D_3, sizes of the ferrite beads and magnitudes of the magnetic fields involved allow bringing their results concerning the oscillation frequency f to the general form $f \sim D^{-1}$. Thus, Dolan [4] operated with coaxial lines of very small diameter ($D_3 \approx 3$ mm) and observed oscillations at a high frequency $f \approx 6$ GHz. A series of our real experiments [9, 10] and simulations [12] with a variety of NLTL diameters also revealed a fair agreement with the formula $f \sim D^{-1}$. With the diameters D_3 varying from 20 to 50 mm the oscillation frequencies changed between 2.3 and 0.9 GHz. Gubanov *et al.* [5] experimented with lines of large diameter ~80 mm and observed oscillations at lower frequencies (0.8 to 2 GHz). Finally, the writers [6] employed TLs of a still larger diameter (275 mm) and obtained oscillations at a much lower frequency, $f \sim 0.3$ GHz. These data point to the decisive role of structural non-uniformity within the waveguide's cross-section as for the laws of EM wave propagation. To clarify the role of individual primary mechanisms, three groups of numerical experiments have been conducted. They concerned excitation of EM modes in a coaxial waveguide partially filled with a magneto-sensitive dielectric medium.

2. NUMERICAL MODELING

The passage through and transformations of the initial carrier-free pulse in the three-sectional transmission line have been simulated numerically for three models of the middle part (the NLTL).The differences in the models related to the internal layer $D_1/2 \le \rho \le D_2/2$ which represents the magnetic-sensitive material. The cases considered were as follows,

(i) Both the ε and μ of the magnetic material are constant scalar magnitudes, however different from the parameters of the outer layer, $D_2/2 \le \rho \le D_3/2$.

(ii) The dielectric permittivity ε is a scalar constant value, while the permeability μ is a scalar dependent on H (isotropic magnetic).

(iii) The layer is a gyrotropic medium (ferromagnet) with a constant isotropic dielectric permittivity.

This choice of model materials permits considering three electrodynamic models of the entire transmission line, namely: model I, an electromagnetically linear one; model II, accounting for nonlinear effects; and model III, a nonlinear and anisotropic model incorporating the L-L equation (2).

A numerical analysis of equation sets (1) and (2) for these models was performed in the FDTD technique [12] and in two dimensions, however still with the limiting assumption of $n = 0$.

2.1. LINEAR MODEL, I

First, consider a linear model where material parameters of both dielectric layers in the middle TL are constant but unequal values. Once again, the outer dielectric possesses μ = 1 and ε = 2.25 as in TL1, whereas the internal dielectric is characterized by μ = 7 and ε = 16. The Landau-Lifschitz equation is not included in the computations, and $\mathbf{B}=\mu_0\mu\mathbf{H}$. The input line TL1 is fed with short 'triangular' pulses with sharp leading edges 0.2 to 3 ns in width, of a 10 ns duration. The simulations show that pulses with a relatively wide front edge (rise times greater than1.5 ns) travel through the line without visible distortions. Contrary to that, a pulse with an initially shorter rise time transforms into a different waveform at the output. Its leading edge spreads wider and oscillations with a decreasing amplitude appear, overlaid on the top (see Fig. 2).

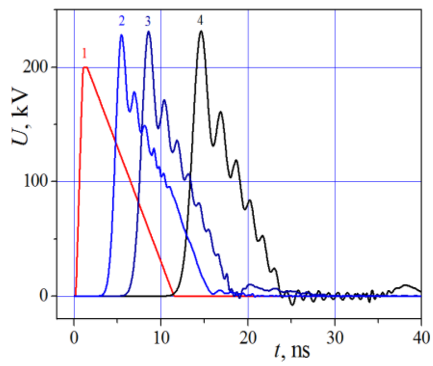

Fig. 2. Model I: Output waveforms of a pulse with t_R = 0.8 ns (curve 1) in TLs of different lengths: L=200 mm (curve 2); L=500 mm (3), and L = 800 mm (4)

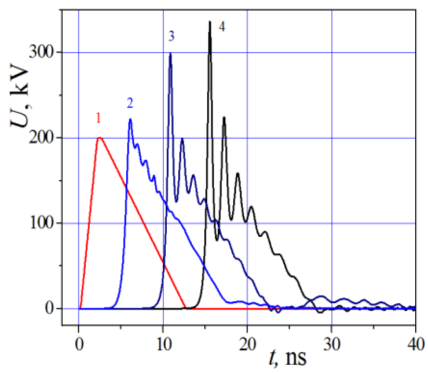

Fig. 3. Model II: Output waveforms of a pulse with t_R=2 ns (curve 1) in TLs of different lengths: L=200 mm (curve 2); L=500 mm (3), and L = 800 mm (4)

Shown in Fig. 4 is a 2D dynamics of the E_ρ, H_φ and E_Z field components in a 'triangular' pulsed electromagnetic wave with parameters U_0 = 200 kV, pulse length $t_{P0.5}$=5 ns and rise time t_R = 0.8 ns. As discussed above, all frequency components of the wideband pulsed signal travel through TL1 in the form of a TEM mode and get scattered at the entrance to the middle part of the line. Some of them get transformed into a dispersive 'quasi-TEM' mode, having acquired a longitudinally oriented electric component, E_z. Others, whose frequencies happen to be close to cut-off

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frequencies of some higher-order TM or TE modes can give rise to these latter, provided that, apart from the frequency proximity, matching also takes place of propagation constants and field vector orientations (polarization). Note that such wave modes (clearly identifiable as TM_{0p}) can be seen in Fig. 4 where they follow behind the main pulse's body as their group velocities are lower than that of the 'quasi-TEM' packet.

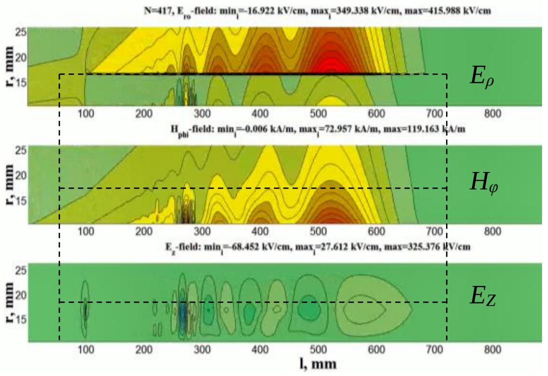

Fig. 4. Model I, linear: Field intensity representations of the E_ρ, H_φ and E_Z components in a 'triangular pulse' form

2.2. NONLINEAR SCALAR MODEL, II

Consider the case where the dielectric constants of both filling materials in the TL are constant values and the medium in the internal layer shows nonlinear magnetic properties. Assuming it to remain isotropic (to emphasize the effects owing to nonlinearity) we write $\mathbf{B}=\mu_0\mu(\mathbf{H})\mathbf{H}$, taking the scalar magnetic permeability to be of form

$$\mu(H_\phi)=1+\frac{M_S}{\sqrt{H_\phi^2+H_0^2}}. \tag{3}$$

Let the saturated magnetization be M_s=300 kA/m, which figure is representative of a lot of ferrite grades. The bias field corresponding to the point of saturation on the 'technical magnetization' curve will be taken as H_0=30 kA/m. The computations show the quasi-periodic oscillations to appear even with a sizable initial width of the incoming pulse (see Fig. 3), unlike the linear case. The rise time t_R of the pulsed wave is reduced in the course of its propagation through the NLTL, *i.e.* the spectrum is enriched in higher frequency components, due to non-linearity, at the expense of low frequencies. This effect of pulse sharpening may become stabilized because of dispersion, in particular near the cut-off frequency of some higher-order mode which would manifest itself as an oscillatory waveform. In the present numerical experiment the width of the pulse's leading edge got stabilized at t_R≈0.4 ns, as measured at the output. At this point, it is worth to compare the oscillation amplitudes at different positions along the TL length, as presented in Figs. 2, 3, for the linear and nonlinear models, respectively. In the linear case, the peak amplitude remains nearly unchanged as the pulse travels along the line (see curves 2-4 in Fig. 2). In the non-linear case (see Fig. 3) the homologous waveform crests in curves 2-4 grow in magnitude as the pulse travels from position 2 to position 4.

This means that the principal energy carrying mode of the NLTL has become coupled to and started pumping energy into the dispersive mode(s) posing as oscillations. The evolution of the E_ρ, H_φ and E_Z field components can be seen in Fig. 5

2.3. NONLINEAR GYROTROPIC MODEL, III

The 'full' nonlinear, gyrotropic model III suggests application of the Landau-Lifschitz equation as a constituent relation for the Maxwell set. Similar as for Model II, the saturated magnetization is M_S=300 kA/m.

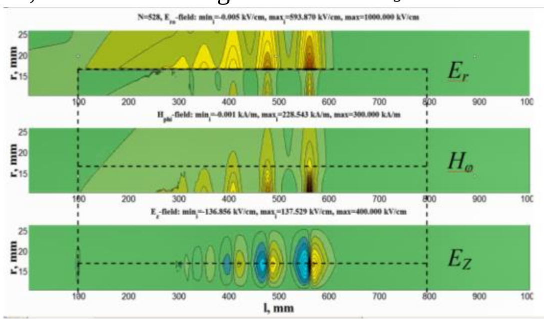

Fig. 5. Model II, nonlinear, isotropic: Field intensity representations of the E_ρ, H_φ and E_Z components in a 'triangular' pulse form

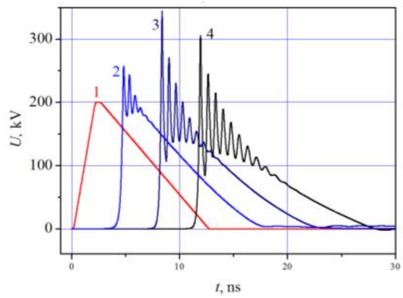

Fig. 6. Model III: Output waveforms of a pulse with t_R = 2 ns at the input (curve1) in TLs of different lengths: L = 200 mm (2); L = 500mm (3), and L = 800 mm (4)

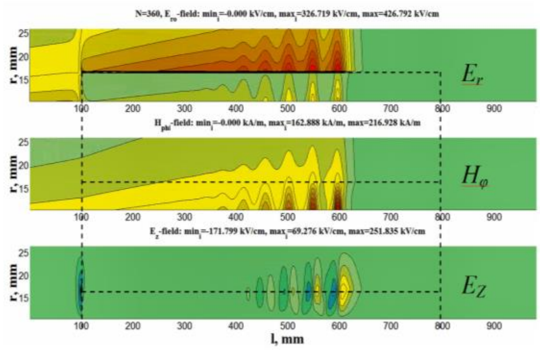

Fig. 7. Model III, nonlinear, anisotropic: Field intensity representations of the E_ρ, H_φ and E_Z components in a 'triangular' pulse form

The relaxation parameter α in (2) equals α = 0.1. The results obtained in the numerical experiment with H_0 = 30 kA/m; U_0 = 200 kV; $t_{P0.5}$= 5 ns, and t_R = 2 ns (an initially broad leading edge) are given in Fig. 6 and Fig. 7. Once again, the pulse voltages estimated at several locations within the NLTL reveal a noticeable growth in amplitude, admittedly as a result of interaction between the now coupled linear eigenmodes.

Also, the oscillation period seems shorter than in the case of Model II. In our view, this may be evidence for involvement of a different, higher-order waveguide mode matched with a small number of frequency components from the 'quasi-TEM' wave packet. The 'quasi-TEM' mode is noticeably dispersive at higher frequencies, hence frequency-selective as for getting in synchronism with other modes.

CONCLUSIONS

The propagation of a short current pulse through a coaxial transmission line that involves a section partially filled with a ferromagnetic material has been analyzed numerically to clarify the role of different physical effects in converting the pulse into quasi-monochromatic radio frequency oscillations. The analysis was performed within three particular models which allowed treating separately the basic effects potentially responsible for the appearance of the oscillations and their amplification and/or decay along the line. Contrary to a widely shared concept, the central frequency of the wideband oscillations is not always associated with the magnetic moment's precession in the ferrite. Depending on the total diameter of the coaxial waveguide, size of the ferrite core, transverse non uniformity of the filling and its electric and magnetic parameters, the oscillations may be represented by various eigenmodes in the line with their specific frequencies and dispersion laws.

REFERENCES

1. I.G. Katayev. Electromagnetic shock waves // *Sov. Radio Publ.Co.* 1963.
2. A.M. Belyantsev, Y.K. Bogatyryov, L.I. Solovyova // *Izv. VUZ - Radiofizika,* 1963, v. 6, p. 551 (in Russian).
3. A.M. Belyantsev, A.I. Dubnev, A.I. Klimin, et al // *(Sov). J. Techn. Phys.* 1995, v. 40, p. 820 (in Russian).
4. J.E. Dolan. Simulation of shock waves in ferrite-loaded coaxial transmission lines with axial bias *// J. Phys. D: Appl. Phys*. 1999, v. 32, p. 1826.
5. V.P. Gubanov, A.V. Gunin, O.B. Kowalczuk, et al. Efficient transformation of high voltage pulsed energy into high frequency oscillations as performed in a transmission line with a saturated ferrite // *J. Techn. Phys. Letters.* 2009, v. 35, № 13, p. 81.
6. V.V. Rostov, N.M. Bykov, D.N. Bykov, et al. Generation of subgigawatt RF pulses in nonlinear transmission lines // *IEEE Trans. on Plasma Sci.* 2010, v. 38, № 10, p. 2681.
7. S.Y. Karelin, I.I. Magda, V.S. Mukhin. A test bed for EMC analyses with ultra-short pulses of complex spectral content // *Problems of Atomic Science and Technology*. 2017, № 6 (112), p. 47.
8. N.P. Gadetsky, S.Y. Karelin, I.I. Magda, et al. Impact of ultra-short wave pulses on the PC // *Problems of Atomic Science and Technology.* 2017, № 6 (112), p. 52.
9. J.-W. Ahn, S.Y. Karelin, H.-O. Kwon, et al. Exciting high frequency oscillations in a coaxial transmission line with a magnetized ferrite // *Korean J. Magnetics*.2015, v.20, № 4, p. 460.
10. J.-W. Ahn, S.Y. Karelin , V.B. Krasovitsky, et al. Wideband RF radiation from a nonlinear transmission line with a premagnetized ferromagnetic core // *Korean J. Magnetics*, 2016, v. 21, № 3, p. 450.
11. Jose Rossi, F.S. Yamasaki, Edl Schamiloglu, et al. Operation analysis of a novel concept of RF source known as gyromagnetic line // *Conf. Paper*. 2017.
12. S.Y. Karelin. A FDTD method for modeling saturated nonlinear ferrites: Application to the analysis of oscillation formation in a ferrite-filled coaxial line // *Radiofizika i electronica.* 2017, v. 8(22), № 1, p. 51 (in Russian).
13. A.G. Gurevich. *Magnetic resonance in ferromagnets and anti-ferromagnets. Nauka Publ .Co. Moscow,* 1973 (in Russian).

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КВАЗИГАРМОНИЧЕСКИЕ ОСЦИЛЛЯЦИИ В КОАКСИАЛЬНОЙ ЛИНИИ С НАМАГНИЧЕННЫМ ФЕРРИТОМ

С.Ю. Карелин, В.Б. Красовицкий, И.И. Магда, В.С. Мухин, В.Г. Синицын

Рассматривается формирование радиочастотных квазимонохроматических осцилляций в топологически двусвязных передающих линиях, заполненных намагниченным ферритом, под воздействием короткого электрического импульса без несущей частоты. Частота и амплитуда возбуждаемых осцилляций определяются дисперсионными и нелинейными характеристиками линии, которые зависят от размеров и геометрии самой линии, а также собственных дисперсионных свойств феррита и слоистой структуры заполнения. Зависимости параметров осцилляций от характеристик системы, установленные в ряде экспериментов, воспроизведены в численных моделях, которые раздельно учитывают указанные характеристики.

КВАЗІГАРМОНІЧНІ ОСЦИЛЯЦІЇ В КОАКСІАЛЬНІЙ ЛІНІЇ З НАМАГНІЧЕНИМ ФЕРИТОМ

С.Ю. Карелін, В.Б. Красовицький, І.І. Магда, В.С. Мухін, В.Г. Сініцин

Розглянуто формування радіочастотних квазімонохроматичних осциляцій під впливом короткого електричного імпульсу без несучої частоти в топологічно двозв'язних лініях передачі, що заповнені намагніченим феритом. Частота й амплітуда осциляцій, що збуджуються, визначені дисперсійними та нелінійними характеристиками лінії, що залежать від її розмірів та геометрії, а також власних дисперсійних властивостей фериту та шаруватої структури заповнення лінії. Залежності параметрів осциляцій від характеристик системи, що були встановлені в низці експериментів, відтворено в числових моделях, котрі враховують вказані характеристики окремо.