ON AN ELECTRON BEAM EXCITATION OF LINEAR IMPEDANCE ANTENNA

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The excitation of linear impedance antenna by an electron beam in an infinite space is considered. The charge of beam is concentrated on one end of the antenna and excites frequency spectrum of its radiation. The system of integro-differential equations for symmetric and antisymmetric Fourier current components with respective boundary conditions is obtained. The solution of the system can be found by the averaging method. The Green function of infinite space and the Fourier transformation are used to calculate the strength of electric and magnetic radiation fields of the antenna.

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Intensive development of nonstationary electrodynamics [1] in last decades arouses considerable interest to impulse - radiating antennas (IRA) or ultra wide-band (UWB) antennas. These antennas find applications in the pulse radio-location [2], ground penetrating radar (GPR) [3], [4], war developments [5], wide-band communication [6]. Original and nonconventional variant of UWB antenna is the antenna, exited by the electron beam [7].

The problem of UWB electromagnetic radiation formation includes two components: the antenna system and the method of its excitation. The curvilinear wire antenna is perspective type of UWB antenna system, because one – wire line, which practically have not frequency dispersion, is its basic element. The electron beam is an efficient instrument of the excitation by charge the antenna. The advantages of the excitation by charge are the followings:

- excitation of the whole spectrum of frequencies, which are inherent to the antenna system (excitation into the end-wall);
- creation of corresponding boundary conditions for the radiated antenna, which is opened at the end (maximum of charge).

The linear impedance antenna is considered as a base model (Fig.).

Boundary conditions are

$$Q(t=0; x=-L) = Q_0\delta(t), \qquad (1)$$

$$Q(t=0; x=+L) = 0 \qquad (2)$$

for the linear density of charge at the ends of an antenna with consideration for the time-space distribution of beam charge on the antenna surface.

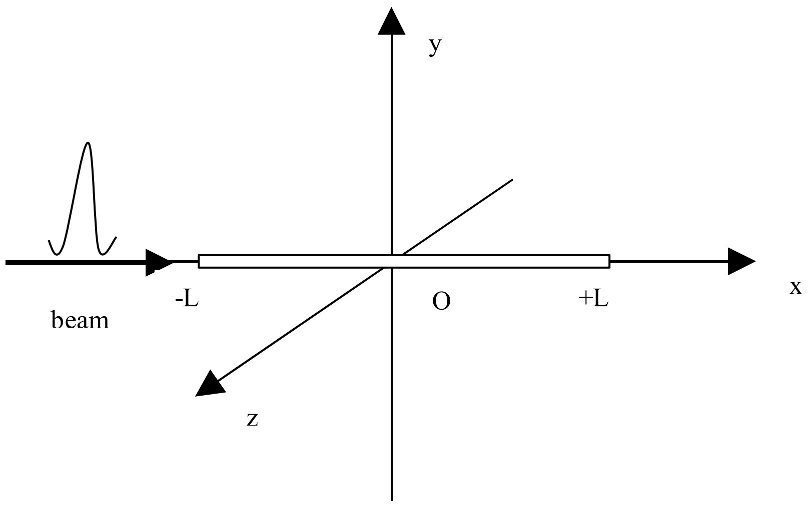
Using the inverse Fourier transformation by the time variable

$$Q(\omega) = \int_{-\infty}^{+\infty} Q(t) e^{-i\omega t} dt, \qquad (3)$$

boundary conditions (1), (2) are rewritten as

$$Q(\omega; x=-L) = Q_0,$$

$$Q(\omega; x=+L) = 0.$$



Symmetric (s) and antisymmetric (a) parts on the space variable are extracted for the spectral component of the linear density of charge

$$Q^{(s)}(\omega,x)=\frac{1}{2}(Q(\omega,x)+Q(\omega,-x)), \qquad (4)$$

$$Q^{(a)}(\omega,x)=\frac{1}{2}(Q(\omega,x)+(-1)Q(\omega,-x)). \qquad (5)$$

Hence we have

$$Q^{(s)}(\omega,-L)=Q^{(s)}(\omega,+L)= =\frac{1}{2}Q(\omega)=\frac{1}{2}Q_0, \qquad (6)$$

$$Q^{(a)}(\omega,-L)=(-1)Q^{(a)}(\omega,+L)= =\frac{1}{2}Q(\omega)=\frac{1}{2}Q_0. \qquad (7)$$

Taking into account the relation [8] (p. 57)

$$\frac{dJ(\omega,x)}{dx}=i\omega Q(\omega,x), \qquad (8)$$

the problem of excitation of the antenna by the arbitrary charge (Q_0) is reduced to the problem of excitation by the spectral component of partial derivative with respect to space variable for the electric current along the antenna.

As this takes place, the symmetric $J^{(s)}(\omega,x)$ and antisymmetric $J^{(a)}(\omega,x)$ spectral components of the current strength along the antenna are described by the system of integro-differential equations [9]

$$\frac{d^2J^{(s)}(\omega,x)}{dx^2}+\frac{\omega^2}{c^2\varepsilon\mu}J^{(s)}(\omega,x)= =\alpha\left[\ F_0^{(s)}\left[x,J^{(s)}\right]+\widetilde{F}_0^{(s)}\left[x,J^{(s)}\right]+F^{(s)}\left[x,J^{(s)}\right]+ +(-1)i\omega\varepsilon\varepsilon_0\dot{Z}\cdot J^{(s)}(\omega,x)\ \right], \qquad (9)$$

$$\frac{d^2J^{(a)}(\omega,x)}{dx^2}+\frac{\omega^2}{c^2\varepsilon\mu}J^{(a)}(\omega,x)= =\alpha\left[\ F_0^{(s)}\left[x,J^{(a)}\right]+\widetilde{F}_0^{(s)}\left[x,J^{(a)}\right]+F^{(s)}\left[x,J^{(s)}\right]+ +(-1)i\omega\varepsilon\varepsilon_0\dot{Z}\cdot J^{(a)}(\omega,x)\ \right], \qquad (10)$$

where ε,μ are, respectively, permittivity and permeability of a medium, in which an antenna is situated; $\alpha=\frac{1}{2}[\ln(2L/a)]^{-1}$ (a is the radius of a vibrator) is the small parameter (α <<1); components of type $F_0^{(s)}\left[x,J^{(s)}\right]$ are the integro-differential operators; $\dot{Z}$ is the internal impedance of a vibrator ($\dot{Z}=\frac{\dot{Z}_s}{2\pi a}$, $\dot{Z}_s$ is the surface impedance of a vibrator).

This system is complemented by the boundary conditions

$$\frac{dJ^{(s)}(\omega,-L)}{dx}=\frac{dJ^{(s)}(\omega,+L)}{dx}= =\frac{1}{2}i\omega Q(\omega)=\frac{1}{2}i\omega Q_0, \qquad (11)$$

$$\frac{dJ^{(a)}(\omega,-L)}{dx}=(-1)\frac{dJ^{(a)}(\omega,+L)}{dx}= =\frac{1}{2}i\omega Q(\omega)=\frac{1}{2}i\omega Q_0, \qquad (12)$$

which follow from (6), (7), (8).

The solution of system (9), (10) with boundary conditions (11), (12) provides in the asymptotic approximation (with a precision to values of the order α^2) a spectral component of current strength along the antenna

$$J(\omega,x)=J^{(s)}(\omega,x)+J^{(a)}(\omega,x), \qquad (13)$$

where $J^{(s)}(\omega,x)$ and $J^{(a)}(\omega,x)$ describe a spectrum of symmetrical and antisymmetric oscillations of current strength.

The strength of electric and magnetic fields, which are radiated by the spectral component of current along the antenna [10] (p.10)

$$\vec{E}(\omega,r)=\left(grad(r)div(r)+\frac{\omega^2}{c^2\varepsilon\mu}\right)\times \times\int_{-L}^{+L}J(\omega,x')\frac{e^{i\frac{\omega}{c\sqrt{\varepsilon\mu}}\sqrt{(x-x')^2+y^2+z^2}}}{\sqrt{(x-x')^2+y^2+z^2}}dx', \qquad (14)$$

$$H(\omega,r)=(-1)i\omega\dot{\varepsilon}\varepsilon_0 rot(r)\times \times\int_{-L}^{+L}J(\omega,x')\frac{e^{i\frac{\omega}{c\sqrt{\varepsilon\mu}}\sqrt{(x-x')^2+y^2+z^2}}}{\sqrt{(x-x')^2+y^2+z^2}}dx'. \qquad (15)$$

Thus, in the linear impedance antenna, which is exited by the beam, the time dependence of electric current is

$$J(t,x)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}J(\omega,x)e^{i\omega t}d\omega, \qquad (16)$$

and in the space-time coordinates radiated the electromagnetic field is

$$\vec{E}(t,r)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}\vec{E}(\omega,r)e^{i\omega t}d\omega, \qquad (17)$$

$$\vec{H}(t,r)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}\vec{H}(\omega,r)e^{i\omega t}d\omega. \qquad (18)$$

Notice that in the case of a curvilinear antenna the system (9), (10) becomes coupled. The analysis of curvilinear impedance antenna of two-dimentional and three-dimentional space configuration can be reduced by the above-given method to the analysis of two and three coupled linear impedance antennas, respectively.

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REFERENCES

1. A.G. Nerukh, N.A. Khizhnyak. *Modern problems of nonstationary electrodynamics*. Kharkov: "Test-radio". 1991, p.250 (in Russian).
2. H.F. Harmut. *Nonsinusoidal wave for radar and radio communication.* New York: "Academic Press". 1981.
3. S. Vitebskiy, L. Garin. Moment method modeling of short-pulse scattering and the resonance of a wire buried inside a lossy, dispersive half-space // *IEEE Trans. Antennas Propagat.* 1995, v.AP-43, №11, p.1303-1312.
4. T.W. Hertel, G.S. Smith. The conical spiral antenna over the ground // *IEEE Trans. Antennas Propagat*. 2002, v.AP-50, №12, p.1668-1675.
5. M. Abrams. Dawn of the E-bomb // *IEEE Spectrum* 2003, №11, p.24-29.
6. N.W. Nurberger, J.L. Volakis. New termination for ultrawide-band slot spirals // *IEEE Trans. Antennas Propagat*. 2002, v.AP-50, №1, p.82-84.
7. N.I. Gaponenko, A.M. Gorbanj, D.V. Goroganin et al. // *Plasma physics*. 2000, v.26, №4, p.1-3 (in Russian).
8. G.T. Markov, D.M. Sazonov. *Antennas*. M.: "Energy". 1975, p.528 (in Russian).
9. S.D.Priyemenko, L.A.Bondarenko Linear impedance vibrator in the circular waveguide // *Telecommunication and Radio Engineering.* 2002, v.56(1-2), p.17-41.
10. N.A. Khizhnyak. *Integral equations of macroscopic electrodynamics.* Kiev: "Naukova dumka". 1986, p.280 (in Russian).

О ВОЗБУЖДЕНИИ ЭЛЕКТРОННЫМ ПУЧКОМ ЛИНЕЙНОЙ АНТЕННЫ

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Рассмотрено возбуждение линейной антенны электронным пучком в неограниченном пространстве. Заряд пучка концентрируется на одном из концов антенны и возбуждает частотный спектр ее излучения. Получена система интегро-дифференциальных уравнений для симметричной и антисимметричной Фурье компонент силы тока с соответствующими граничными условиями. Решение системы может быть найдено методом усреднения. Функция Грина неограниченного пространства и преобразование Фурье используются для получения напряженности электрического и магнитного полей, излучаемых антенной.

ПРО ЗБУДЖЕННЯ ЕЛЕКТРОННИМ ПУЧКОМ ЛІНІЙНОЇ АНТЕНИ

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Розглянуто збудження лінійної антени електронним пучком у необмеженому просторі. Заряд пучка концентрується на одному з кінців антени і збуджує частотний спектр її випромінювання. Отримано систему інтегро-диференційних рівнянь для симетричної і антисиметричної Фур'є компонент сили струму з відповідними граничними умовами. Розв'язок системи може бути знайдено методом усереднення. Функція Гріна необмеженого простору і перетворення Фур'є використовуються для одержання напруженості електричного і магнітного полів, що випромінюються антеною.