SCATTERING PROPERTIES OF CARBON NANOTUBE ANTENNAS

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Abstract

The boundary problem of diffraction and excitation of system of nanotubes-vibrators was reduced to solution of the integral equation (IE) with logarithmic kernel. After regularization the IEs were solved by means of collocation method considering th current's behaviour at the vibrator's endings. The existence of resonances in the frequency range 0,1-1,0 THz was shown.

Keywords: Carbon nanotubes, CNT, nanovibrators, quantum resistance, collocation method, integral equations.

1. INTRODUCTION

In recent years due to development of investigation of carbon nanotube's properties some new approaches to it's application are ariving. One of the applications is their use as the new class of antenna devices. Nanotubes have quantum resistance, which, in differ to ohmic resistance of metallic wire, is not inversely proportional to it's radius and it's value is much less than resistance of copper wire of the same radius. Even at frequencies about 1 THz the skin-effect in nanotubes can be neglected. Though in [1,2] the low efficiency of such CNT antennas is shown, the detailed investigation of their characteristics is necessary to determine optimal parameters of nanotubes, which can lead to creation of antenna systems with acceptable properties.

The carbon nanotubes are of great interest due to the possibility of it's application as antennas for different areas: nano-inerconnect in nanocurcuits, fiber optics, connection for aviation. Their advantages are small sizes, light weight, outstanding electrical properties. Because the length of carbon nanotubes can be up to several centimeters, it's naturally to consider them as antennas in centi- and millimeter frequency ranges. They can be also used to connect nantocircuits to macroscopic world, even to power the nanocircuit from external radiation.

2. CONTENTS

The solution of the problem is based on far field determination through vectorial potential, created by current, flowing on the surface of the nanotube. Assuming that surface current $j(z')$ has only longitudinal part, which doesn't depend on the angle φ, and that the current at the ends is missing, the vectorial potential, created by the current, is [3]:

$$A(z) = 2\int_{-l}^{l} j(z')g_1(z,z')dz' ,$$

$$g_1(z,z') = \frac{a}{4\pi}\int_0^{2\pi} \frac{d\phi}{R(z,z')} e^{-ikR} \approx$$

$$\approx g_0(z,z')e^{-ik|z-z'|},$$

$$R = \sqrt{2a^2(1-\cos\phi) + (z-z')^2} ,$$

$$g_0(z,z') = \frac{a}{4\pi}\int_0^{2\pi} \frac{d\phi}{R} = \frac{1}{2\pi} PK\left(P\right),$$ where $K\left(P\right)$ - full elliptical integral of the 1-st kind,

$P = 2a\Big/\sqrt{4a^2 + \left(z-z'\right)^2}$, $2l-$ vibrator's length, $a-$ it's radius.

The field is expressed by following integral:

$$\vec{E}\left(z\right) = \frac{1}{i\omega\varepsilon\varepsilon_0}\left[\frac{\partial^2 A}{\partial z^2} + k^2 A\right] + E^e\left(z\right) \qquad (1)$$

where $E^e\left(z\right)$ - external field,

Let's satisfy boundary condition at the surface of the vibrator:

$$E_z = \rho_n j, \qquad (2)$$

ρ_n - surface resistance. The dependence of surface conduction of CNT on frequency is taken in [1]. Substituting (1) in (2) we obtain integro-differential equation (IDE) in j . This IDE was reduced to the integral equation (IE) using 1-d Green function. This IE was solved by means of collocation method and isolation of singular part of the kernel (analogous to [3]).

Using developed algorithms and software the calculation of dependencies of input impedance and voltage in the gap of nanotube-vibrator on the frequency was performed. The dependency of real part of input impedance (normalized to 12,9kOhm, [1]) on frequency for the system of two parallel nanotubes with diameter 0,678 nm and length 20 mkm, distant one from another on 0,25 mkm is shown on the fig.1.

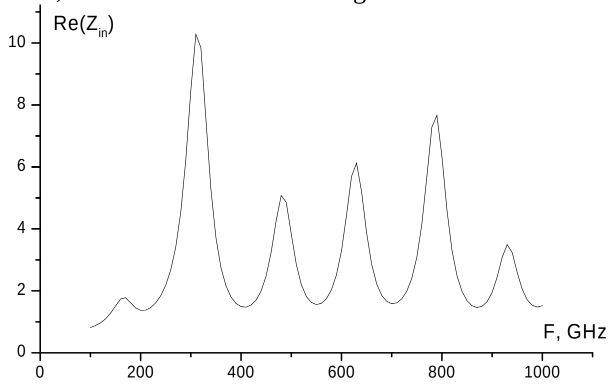


Fig. 1. The dependence of input impedance on frequency (real part); *a*=0.678 nm, *l*=10 mkm, *d*=0.25 mkm.

On the fig. 2 the analogous dependence for the same system of imaginary part of Z_{in} is presented:

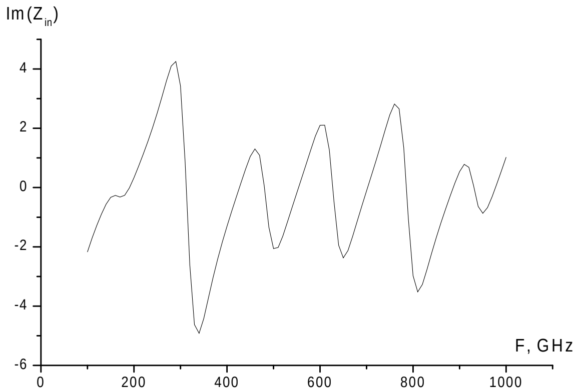


Fig. 2. The dependence of input impedance on frequency (imaginary part);a=0.678 nm, l=10 mkm, d=0.25 mkm.

On the fig.3 the dependence of voltage in the gap of vibrator for the diffraction problem on frequency is presented.

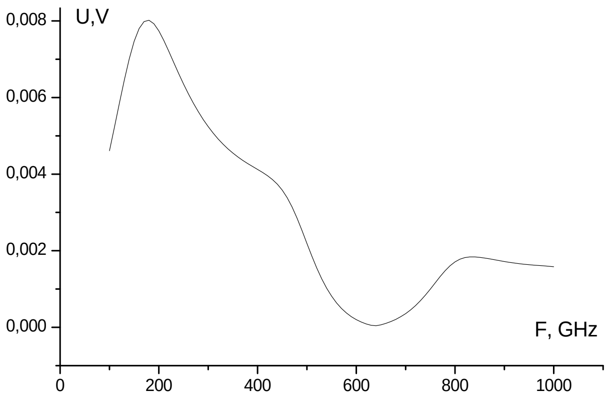


Fig. 3. Dependence of voltage in the vibrator's gap. a=0.678 nm, l=10 mkm, d=0.25 mkm.

The results of fig.1-3 allow us to conclude that there are some resonances in the frequency range under investigation for such system of CNT's

On the fig. 4 the analogous results are presented for single nanotubes with radius 0,339 nm and of different lengths.

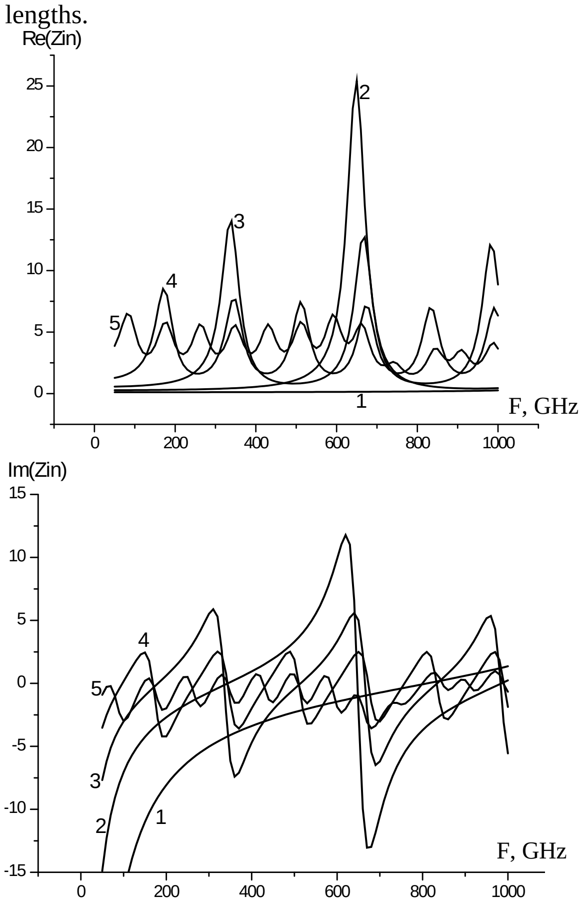
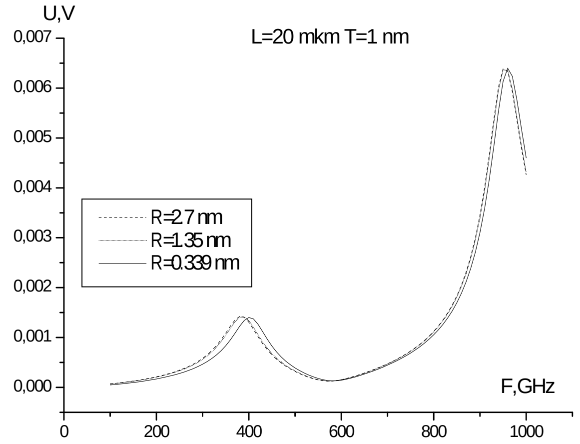


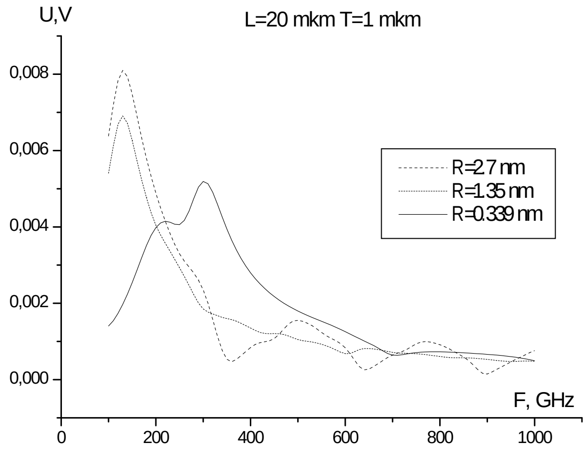
Fig. 4. Dependencies of input impedance on the frequency; curves: 1 – l=2mm, 2 – l=5mm, 3 – l=10mm, 4 – l=20mm, 5 – l=40mm.

We can see that an increase of CNT's length leads to an increase of number of resonances, and at the same time it leads to the decrease of input impedance value.

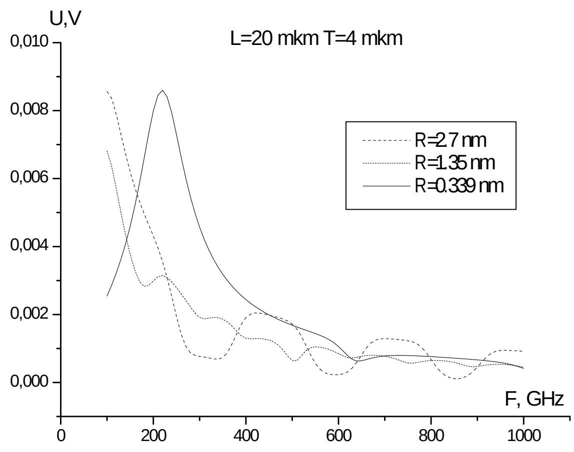
The results of calculation of voltage at the gap of nanotube in the system of 10 parallel CNT's, distant one from another on length T are presented on the fig.5. The calculation performed for the systems of CNT's with different radiuses R=2.712 nm, R=1.356 nm, R=0,339 nm.We have computed the voltage only on the first nanotube in the system, because for all considered CNT's configuration the dependencies of the voltage in the gap of all nanotubes from the system were very close.



a)



b)



c)

Fig. 5. The results of calculation of voltage for the systems of CNT's.

We can see the strong mutual influence, especially for nanotubes with R=0,339 nm. In the case of closely spaced nanotubes (T=1 nm), the bundle of which was considered in [4], one can conclude that strong mutual influence leads to vanishing of low-frequency maximums and to rise of maximum in high-frequency range. Also we can see, that for closely spaced CNT's there is no difference between nanotubes of different radiuses.

CONCLUSION

In conclusion we'd like to say that all investigated CNTs demonstrate resonance of input impedance in the frequency range of 100-1000 GHz. The dependence of gap voltage changes greatly for the system of nanovibrators with different distances between nanotubes, especially for nanotubes with R=0,339 nm.

REFERENCES

1. Hanson G.W. Fundamental Transmitting Properties of Carbon Nanotube Antennas. //IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, Vol.53, N.11, 2005, p.3426-3435
2. Yi Huang and Wen-Yan Yin. Performance predication of carbon nanotube bundle dipole antenna. //Proceedings of Asia-Pacific Microwave Conference 2007.
3. Lerer A.M., Kleschenkov A.B., Lerer V.A., Labunko O.S. //Radiotehnika I elektronika, V.53, No.4, 2008, pp. 423–431.
4. Kleschenkov A.B., Lerer A.M., Makhno P.V., Makhno V.V. Electrodynamic analysis of carbon nanotube antenna. 12th International conference on Mathematical Methods in Electromagnetic Theory (MMET-2008), 2008, Odesa, Ukraine.