

Scattering Control Using Nonlinear Smart Metasurface with Internal Feedback

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Abstract. The ideology of creation of a nonlinear smart metasurface with internal feedback for the adaptive control by spectral composition of scattered field is offered. The metasurface contains a lattice of strip elements with nonlinear loads-sensors. They are included in a circuit of internal feedback for the adaptive control of scattered field. Numerically it is shown that maximal levels of the second harmonic in the spectrum of scattered far field correspond to maximum of voltage rectified on metasurface. Experimentally the prototype of the plane smart covering on the basis of the metasurface in the form of strip lattice with controlled nonlinear loads-sensors is investigated for an idea confirmation.

1. Introduction

Nonlinear metasurfaces (NMSs) on the basis of controlled nonlinear loads (NLs) are applied in different microwave, terahertz and optical devices [1-3]. The NMSs can potentially contribute to developing a new type of an applications of smart artificial surface [2]. Designing of smart NMSs requires the organization of adaptive control of nonlinear scattering. However, generally in a control system of scattering there is no trustworthy information about characteristics of far field.

Irradiation by means of the harmonic field of nonlinear metasurfaces with controlled NLs leads to appearance of the side reradiation at frequencies of harmonics and combinative spectral components of the main signal. Levels of the reradiated fields at frequencies of harmonics are functionally connected to the NL parameters, in particular, with a voltage rectified on NLs with the square voltage-current characteristic (VCC). Thus, NLs with the controlled VCC parameters allow to control the spatial-frequency spectrum of scattered field [4].

In this paper the creation of a nonlinear smart metasurface with internal feedback for the adaptive control by spectral composition of a scattered field is considered. The metasurface contains a lattice of strip elements with nonlinear loads-sensors included in a circuit of internal feedback.

2. Analysis of theoretical results

In paper [4] the solution of a problem of a scattering of a plane monochromatic wave by the infinite periodic lattice of the strip elements (the left part of figure 1) having nonlinear loads (NLs) was resulted using method of nonlinear integral equations. Unit cell of investigated NMS on the substrate with ground plane is shown in the right part of figure 1. It is built on the base of the nonlinear lattice. The metasurface contains a lattice of strip elements with nonlinear loads. The VCC of NL was set as

$$i^e = \sum_{v=0}^P (a_v u(t)^v + b_v du^v(t) / dt),$$



where i , u are current through load and voltage on load terminal pair; a_v , b_v are the coefficients determined by electrophysical properties of load; t is time.

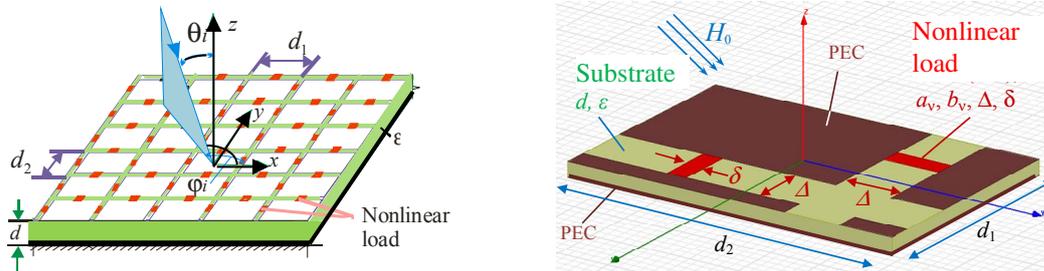


Figure 1. Statement of the problem of scattering of incident plane wave (with amplitude H_0 and angles incident of θ_i , ϕ_i) by the infinite periodic lattice of the strip elements with NLs (left) and unit cell of nonlinear metasurface on the substrate with ground plane (PEC): $d_1 = d_2 = 5$ mm, $\Delta = \delta = 1$ mm, $d = 0.3$ mm, $\varepsilon = 2.74$ (right).

The lattice of strip elements was located on the dielectric substrate of permeability ε and thickness d above the ground.

Stages of solution included [5]: obtaining of nonlinear boundary conditions regarding harmonics of electric and magnetic surface currents $J_{nx}^{e1,2}$, $J_{ny}^{m1,2}$ on loads; obtaining of the nonlinear integral equation system; obtaining of nonlinear algebraic equation system; numerical solution of the nonlinear algebraic equation system regarding harmonics of magnetic surface currents on $z=0$ -plane; defining of harmonics of scattering field or other scattering characteristics. Dependences of the constant component of the voltage (induced by incident wave) on inputs of NL [4] as well as dependences of lattice reflection coefficients from parameters of loads and the incident plane electromagnetic wave are investigated. Value of rectified (in the load) voltage U_0 is defined by values of zero-order harmonics of magnetic surface currents on NLs (they found in result of the numerical decision of system of nonlinear integral equations [4]). Reflection coefficients $|R_n^{jk}|$ show the attitude of amplitudes of (j,k) -th Floquet's harmonics of fields, reflected from the lattice at frequencies of n -th harmonics, to amplitude of the incident field at fundamental frequency f_1 (in case of $n=1$).

Let us analyze the dependences of the rectified (on the load) voltage versus the bias voltage applied to the load and of the distance from the scatterer to the source of the probing signal. We will consider that charts of rectified voltages versus bias voltage are similar to dependences of reflection coefficients versus coefficients of loads' polynomial VCC. Charts of rectified voltage versus distance are similar to dependences of reflection coefficients versus amplitude of the irradiating wave. In figure 2 rectified voltage versus coefficient a_2 of square term of the VCC is shown. The sizes of the lattice are set so that at these frequencies they belong the single-mode area of periodicity. Calculations are given for the passive lattices having loads with the positive linear conductivity a_1 . Rectified voltage U_0 with growth of a_2 increases quadratically at first, and then almost linearly. In case of some coefficient $a_2 = a_{2max}$ the voltage reaches the maximum. The a_{2max} is defined by linear admittance of the load as well as absolute and relative geometrical sizes of the load (in comparison with the unit cell sizes). In figure 3 reflection coefficients of zero-order Floquet's mode $|R_n^{00}|$ at fundamental frequency ($n=1$), the second ($n=2$) and third ($n=3$) frequency harmonics versus coefficient a_2 of square term of the V C are shown. In the case of passive loads the reflection coefficient of zero-order Floquet's mode on the second frequency harmonic also reaches the maximum in the case of $a_2 = a_{2max}$.

Means, in case of this value of a_{2max} , the greatest redistribution of energy of incident wave at harmonic frequencies is carried out; the efficiency of conversion of wave energy to rectified voltage will be maximum. In the case of increase in values $a_2 > a_{2max}$ values of $|R_2^{00}|$ and $U_0(a_2)$ decrease. It can

be explained by a changing of a shape of load VCC from close to characteristic of diode detector (in case of $a_2 \leq a_{2max}$) on almost parabolic (in case of $a_2 \gg a_{2max}$).

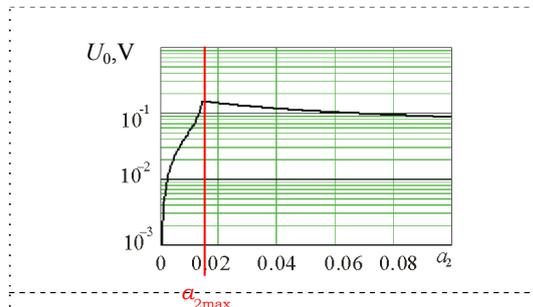


Figure 2. Rectified voltage U_0 versus coefficient a_2 of square term of the VCC.

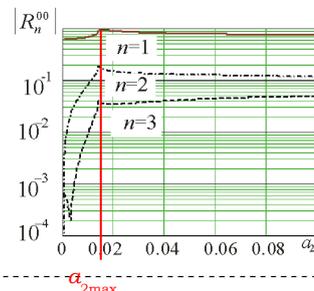


Figure 3. Reflection coefficients versus coefficient a_2 of square term of the VCC.

Nature of dependence of rectified voltage U_0 versus amplitude H_0 of incident wave (figure 4) is also defined by a ratio of VCC coefficients of NLs (i.e. a type of VCC). When VCC about origin of coordinates has the type close to the characteristic of the diode detector (curve 1* in inset of figure 4), for some H_0 the value of rectified voltage reaches a maximum, and then decreases (in some range of increase of H_0). In case of other VCC types of loads (“cubic” and “parabolic”, see curves 2*, 3* in inset of figure 4), diagrams have the sections of square growth in case of $H_0 < 0.2$ A/m and slower growth in case of $H_0 > 0.2$ A/m.

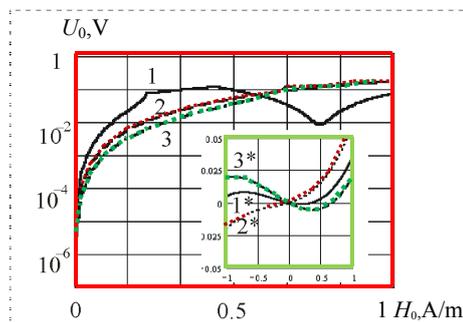


Figure 4. Rectified voltage versus of incident wave amplitude for $\theta = 0$.

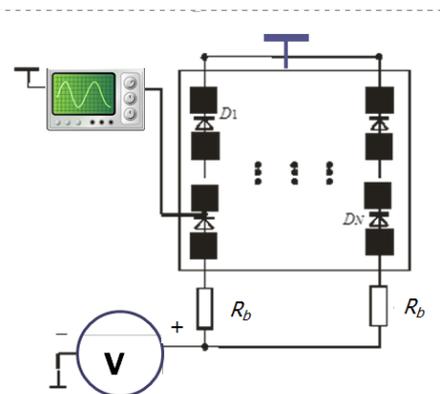


Figure 5. Equivalent scheme circuit of the prototype.

3. The analysis of the experimental characteristics of the prototype

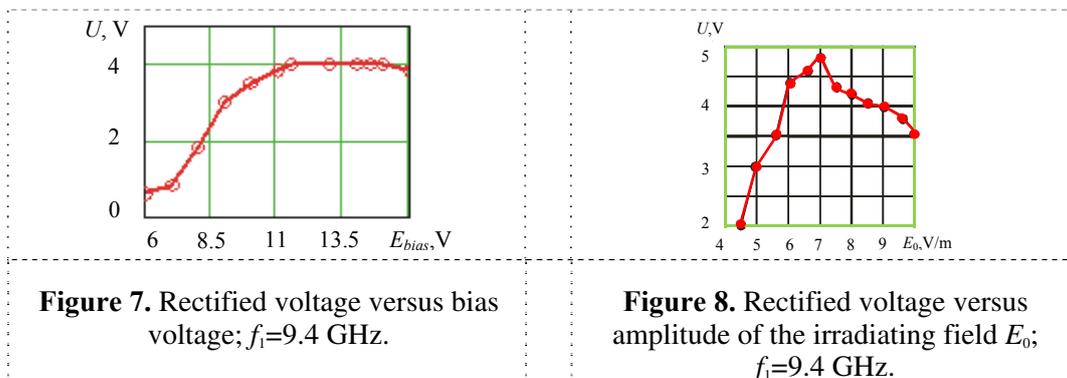
The prototype of the plane smart covering on the basis of NMS with internal natural feedback (figure 5) represents the finite lattice of square strip elements. Between their edges the diodes are placed in one of the directions. On the diodes the bias voltage is served. From the diodes at the same time with bias voltage the rectified voltage is removed. For achievement of necessary bias voltage, diodes are switched on sequentially on columns through balance resistance, and columns of diodes are paralleled. Rectified voltage was measured on one diode or on a column of diodes. The photograph of a prototype of the microstrip lattice with nonlinear loads is shown in figure 6.

In figure 7 the dependence of the rectified voltage on one diode, measured across the integrating capacity, versus bias voltage is shown. It is visible that there is the optimum of bias voltage given on one diode. At the same time the maximum of rectified voltage is watched that is unambiguous connected to a maximum of far field on the second harmonic $n = 2$ (see figure 2).

Also the rectified voltage on a column of diodes is measured versus amplitude of the irradiating field E_0 . It is visible that results of experiment (figure 8) and calculation (figure 4) match qualitatively.



Figure 6. The prototype of the microstrip lattice with nonlinear loads: front side (left) and back side (right).



4. Conclusion

The obtained results have allowed to offer the ideology of creation of a nonlinear smart metasurface with internal feedback for the adaptive (to the changing excitation conditions) control by spectral composition of far field. Information about the rectified voltage and tuning of bias voltage toward maximum of the rectified voltage provide the greatest transfer of energy at the frequency of the second harmonic and enrichment of a spectrum of the reradiated signal.

Acknowledgement

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