UDC 621.396.946

MUTUAL COUPLING COEFFICIENTS BASIC AND HIGHER MODES OF SPHERICAL DIELECTRIC RESONATORS

Trubin A. A.
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
E-mail: atrubin9@gmail.com

КОЕФИЦІЕНТИ ВЗАЕМНОГО ЗВ'ЯЗКУ ОСНОВНИХ ТА ВИЩИХ КОЛИВАНЬ СФЕРИЧНИХ ДІЕЛЕКТРИЧНИХ РЕЗОНАТОРІВ

Вперше досліджуються коефіцієнти взаємного зв'язку між коливаннями основних та вищих типів. Знайдено нові загальні аналітичні вирази для коефіцієнтів взаємного зв'язку діелектричних резонаторів сферичної форми. Досліджуються властивості зв'язаних коливань нижчих типів з коливаннями шепочущей галереї. Результати досліджень є основою для побудови різноманітних оптичних пристроїв для систем оптичного зв'язку.

Today, high-quality spherical dielectric resonators are important elements suitable for further use in a variety of communication devices [1 – 8]. Currently, DRs with whispering gallery oscillations are mainly used in the optical and infrared ranges [3 – 5]. These oscillations have a very high quality factor, but their frequency spectrum is quite dense. One of the effective ways to rarefy the frequency spectrum is to use coupled resonators with different types of natural oscillations. In addition, in some devices, such as power dividers, it is assumed that DRs with different types of oscillations will be used. To model the electromagnetic parameters of such devices, it is necessary to know the coefficients of mutual coupling between resonators of different types. In this case, it is desirable to have analytical expressions for coupling coefficients, since the speed of calculating the parameters of more complex structures based on them increases many times.

In works [9, 10], the coefficients of mutual coupling of spherical DR in open space already have been studied. We found general analytical expressions for the coupling coefficients of DRs of different types, obtained in the form of complex integral expansions. It was shown that the above general formulas can be calculated in quadratures, in the form of a series, using a generalization of the Somerfeld integral [11], however they require the calculation of rather cumbersome coefficients expressed through 3-j Wigner symbols. This study examines simpler special cases of accurately calculating coupling coefficients between spherical DRs of different sizes, one of which is excited by the main magnetic or electrical mode of oscillations. The natural oscillations of the second DR can be anything. As a result, we obtained new exact analytical formulas for complex coupling coefficients: $\kappa_{12} = \kappa_{12}(\Delta\theta, \Delta\alpha, k_0\Delta r)$ without additional expansions. Where in the spherical coordinate system of the first DR, the vector $(\Delta r, \Delta\theta, \Delta\alpha)$ determines the coordinates of the center of the second resonator.

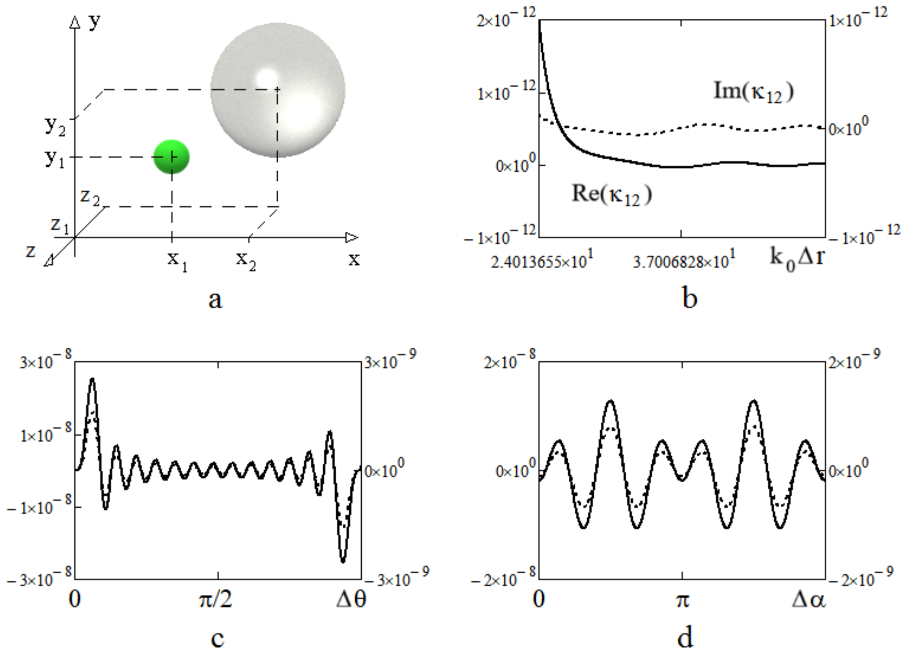

Fig. 1. Different spherical DR with main and higher oscillations (a).
The coupling coefficients of two different DR with $H_{1,m,1}$ and $H_{5,30,1}$ as functions of the distance between resonator centers (b) ($\Delta\theta = 1,3$; $\Delta\alpha = 2$); as a function of changing angles (c, d) ($\Delta\alpha = 0$ (c); $\Delta\theta = 1,4$ (d); $k_0 \Delta r = 17$) for $\varepsilon_{1r} = 25$; $\varepsilon_{2r} = 2,25$.

On Fig. 1 shows an example of calculating the dependences of the DR coupling coefficients, the dimensions of one of which correspond to the possibility of the existence of the main magnetic oscillation H_{1m1}, and the second the existence of a magnetic oscillation of the whispering gallery $H_{5,30,1}$. The dependence of the real (left ordinate axis) and imaginary part (right ordinate axis) on the distance between the centers of the resonators is shown in Fig. 1, b, and with variations in angular variables, in Fig. 1, c, d. Solid lines show the dependences of the real part, and dotted lines show the dependences of the imaginary part of the coupling coefficients. As one would expect, the maximum values of the real part of the coupling coefficients, corresponding to the splitting of the frequencies of coupled oscillations, in most cases are established in the region adjacent to the surface of the resonator with whispering gallery oscillations (Fig. 1, b). As the resonators move away from each other, the coupling coefficients quickly decrease.

The general picture of the distribution of the real part of the mutual coupling coefficients of resonators in the plane $|k_0 \Delta z| = 0,1$ for different types of oscillations is shown in Fig. 2, a–c.

Thus, the obtained analytical expressions for the mutual coupling coefficients of the basic and higher types of spherical DR oscillations make it possible to construct electromagnetic models of a wide class of devices in the optical and infrared range.

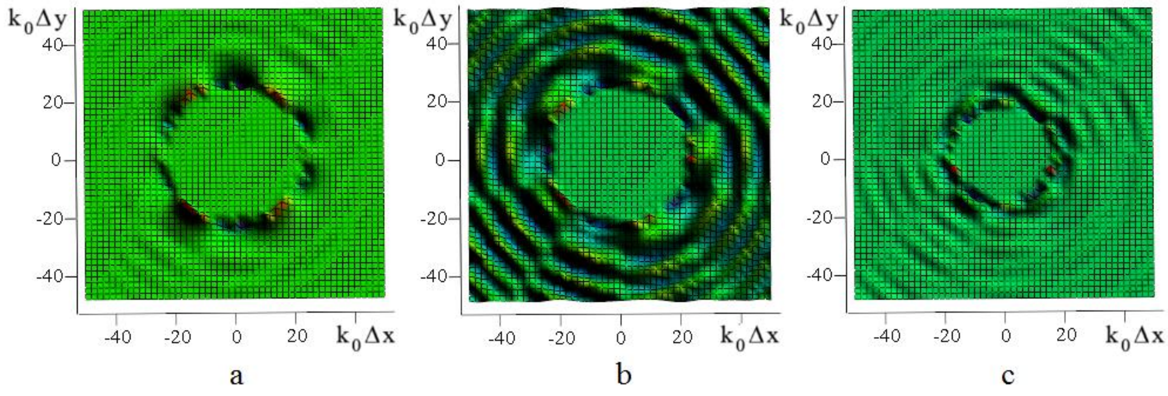

Fig. 2. Distribution of the real part of the coupling coefficients from the coordinates of the resonators in the plane (x, y) for $H_{1,1,1}$ and $H_{5,30,1}$ oscillations (a); $H_{1,0,1}$ and $H_{5,30,1}$ oscillations (b); $H_{1,0,1}$ and $E_{5,30,1}$ oscillations (c).

The considered systems of coupled resonators can be used in various elements of optical communication systems: antennas, sensors, channel switches, etc.

References

1. P. Salzenstein, M. Mortier, H. Serier-Brault, H. Remi, A. Coillet, Y.K. Chembo, A. Rasoloniaina, Y. Dumeige, P. Feron, Coupling of high quality factor optical resonators // Physica Scripta, vol. 157, 2013, pp. 014-024.
2. Mitsui T., Onodera T., Wakayama Y., Hayashi T., Ikeda N., Sugimoto Y., Takamasu T., Oikawa H. Influence of micro-joints formed between spheres in coupled-resonator optical waveguide // Optics Express. 2011 , Vol. 19, No. 22. PP. 22258-22267.
3. Xifré-Pérez E., Domenech J.D., Fenollosa R., Munoz P., Capmany J., Meseguer F. All silicon waveguide spherical microcavity coupler device // 2011/ Vol. 19, No. 4 / Optics Express. PP. 3185-3192.
4. Righini G. C., Dumeige Y., Feron P., Ferrari M., Nunzi Conti G., Ristic D., Soria S. Whispering gallery mode microresonators: Fundamentals and applications // Rivista del Nuovo Cimento, 2011, vol. 34, N. 7, pp. 435 - 488.
5. Astratov V. N. Ch. Fundamentals and Applications of Microsphere Resonator Circuits. Photonic Microresonator Research and Applications. Springer. 2010. PP. 423-457.
6. Thompson D.B., Keating D.A., Guler E., Ichimura K., Williams M.E., Fuller K.A. Separation-sensitive measurements of morphology dependent resonances in coupled fluorescent microspheres // Optics Express. 2010 , Vol. 18. No. 18. PP. 19209 - 19218.
7. A. Kirichenko, Yu. Prokopenko, Yu Filipov, N. Cherpak "Qasioptical solid-state resonators" Kiev: Naukova dumka, 2008, 286 p.
8. Chen Z., Taflove A., Backman V. Highly efficient optical coupling and transport phenomena in chains of dielectric microspheres // February 1, 2006 / Vol. 31, No. 3 / Optics Letters. PP. 389-391.
9. Trubin A.A. Coupling coefficients of the Spherical Dielectric Micro-resonators with Whispering gallery modes // Bulletin of NTUU "KPI" ser. Radiotechnique, Radioaparatus Building. 2015. N.62, pp. 49-61.
10. Trubin A.A. Coupling coefficients of different Spherical Dielectric Microresonators // Information and Telecommunication Sciences, 2018, V. 9, No 1, pp. 49-56.
11. A.A. Trubin. Lattices of Dielectric Resonators. Springer International Publishing Switzerland – 2016 – 171 p.